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LENS-WORK FOR AMATEURS

BY
HENRY ORFORD

AUTHOR OF "MODERN OPTICAL INSTRUMENTS," ETC.

REVISED BY
A. LOCKETT

AUTHOR OF "CAMERA LENSES"



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PREFACE

It must not be supposed that I make any pretence in the following pages to give an easy or simplified method for the manufacture of lenses. Of all branches of handiwork this is perhaps the most difficult, and most abounding in disappointment to the inexperienced, and no amount of theoretical or mathematical knowledge will supersede many hours of careful and often wasted labour. But I have endeavoured to make my practical instructions as plain as possible, and to adapt them to the requirements of young workers as well as amateurs, and hope that they may serve as an introduction to the several excellent works on the subject which are already in use.

HENRY ORFORD.

SEAFORD.

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LENS-WORK FOR AMATEURS



CHAPTER I

A LENS DEFINED ; DISTINGUISHING NAMES OF LENSES ; SPHERICAL ABERRATION AND CAUSE OF ACHROMATISM.

IN this work I shall describe the grinding, finishing, setting, testing, and the computing of lenses, as a guide to the amateur. Most of the tools required can be made by any one having a slight knowledge of turning. The most important part is getting them to the curve, and in contact. This is accomplished by grinding and rubbing. Do not get the gauge to the tool, as I detected a pair of worthies once doing, when they had a quantity of tools to rub that had been worked away from their curves. They found it easier to get the gauges to the tools than the tools to the gauges, and there have been several unaccountable failures in their computations since that event.

Many of the failures of amateur lens-workers are caused by their total neglect of the first principles of optics. They will often alter a lens without the least thought, and not improving it, will give it a final dose of working, and then it goes to limbo. Some two

years ago a gentleman friend of mine took to dabbling in optics, and he used to come and show me the results of his work, and ask for a few hints. I thought little of his attempts at first, but in time I had to confess he was getting "in the know," and he can now make a very creditable objective. He was a long while before he could grasp the first principles. He used to start with a pair (a flint and crown) and alter to see "what came of it," until he was perfectly conversant with the alterations necessary for correcting either under- or over-chromatic aberration, and he now considers himself a competent rule-of-thumb optician.

One thing a beginner is prone to do is to overlook a slight defect in thickness and curvature, and think, "Well, it is very little, and can make no difference"; but, if the work takes longer, the time is always well spent, for neglecting only a little leads to failure. Much can be done by rule of thumb, but, of course, one must have a good experience at the work; but it is not used so much now. A system can be computed by mathematics that will be perfect at the first working; whilst by rule of thumb or correcting by results it is generally a long job even now, with the quantity of glass in the market of different specific gravities, refractions, and dispersions, and one can correct in some cases by alteration of glass alone, without touching the old curves. One thing these extensive varieties of glass have done is to make the copyist's work more complicated. In the old times he could get hold of a lens, take the curves, and there being so few

kinds of glass in the market, it was comparatively easy to hit on the glass.

As an instance of the precision a system can be calculated to by mathematics, the following will speak for itself:—Whilst I was engaged practically carrying out the computations of Dr. Hugo Schroeder, I had a deep-water immersion system to make. He had calculated the curves, thicknesses, and distances. His drawing was given to me to carry out, and the lens when finished was perfect; no alteration could possibly improve it. A lens could, of course, be corrected as well by a competent workman, in some cases in less time than it would take a mathematician to calculate it; but at the same time the mathematician will always be within reasonable distance of the goal desired, while the rule-of-thumb workman will often flounder out of his depth altogether. In these chapters I shall endeavour to combine the two systems, getting a foundation by mathematics and finally correcting by results. Before we start the theory of achromatising lenses we must learn to work a surface; and as it is a waste of time to work a thing that would be useless, we will first try our hand on an easy photographic combination.

First, let us have a few examples of what a lens is, the action of a pencil of light passing through it, and why a single lens could not be made achromatic.

A lens is a portion of a refracting medium (the term “medium,” for our purpose, means any transparent substance) bounded by two spherical surfaces which have

a common axis ; if these surfaces do not meet, the lens is supposed to be bounded by a cylinder having the same axis as the spherical surfaces.



Fig. 1.



Fig. 2.



Fig. 3.

Lenses receive distinguishing names according to their forms. If thicker in the middle they are known as convex ; if thicker at the edges, concave. Most lenses are spherical, each curve forming part of a sphere, but cylindrical and parabolic lenses are also in



Fig. 4.



Fig. 5.



Fig. 6.

use for special purposes. Fig. 1 is a double-convex, or biconvex ; Fig. 2, crossed convex, with sides of unequal curvature ; Fig. 3, plano-convex ; Fig. 4, biconcave ;

Fig. 5, crossed concave ; Fig. 6, plano-concave ; Fig. 7, convex meniscus ; Fig. 8, concave meniscus ; Fig. 9, parabolic ; Fig. 10, cylindrical plano-convex.

The rays forming any pencil of light must be either parallel, convergent, or divergent, and when a parallel pencil of light passes through a convex lens the rays are made convergent, and converging rays are made more convergent still.

When a pencil of rays proceeding from a point of



Fig. 7.

Fig. 8.

Fig. 9.

Fig. 10.

an object passes through a simple convex lens, the rays, owing to the spherical curves, do not all come to a focus at the same distance, the central rays being focussed a little farther off than the marginal rays. This is called spherical aberration and causes an indistinct image. It can be neutralised by a suitable combination of curves.

In an incident pencil of light interrupted for the first time by a lens, the rays are all central—that is, their axes all pass through the centres of the lens ; but the pencils upon emerging from the first lens are

already determinate both in extent and direction, and consequently some of them will fall eccentrically upon a second lens—that is, their axes will meet this lens at different distances from the centre. The axes of most of the eccentrical rays will then after emergence cross the axis of vision nearer to the lens than will those of the more nearly central pencils; and whilst the centre of the object will be well defined, the marginal portions of the image will be confused. This confusion at the margin is called spherical confusion.

When an image is formed by a single lens, the light which passes through not being homogeneous, will be dispersed by the lens in two different ways. First, the coloured images will be distributed at different distances along the axis of the lens; and second, the coloured images will be of different diameters.

In an achromatic pair, such as a telescope objective, two lenses are cemented together to act as one lens; then a point and its image lie on one line through the centre of the combination, and if the lenses are corrected so that the different coloured images all lie on the same plane, perpendicular to the axis, they will all have the same diameter.

In a pair of lenses being made of crown and flint glass, the flint having a higher dispersive power than the crown, the crown will be double convex, and the flint double concave. We shall see how the correction may be effected. By the convex lens the coloured images will be formed at different distances along the axis, the violet image being nearest the lens, and the red image

the most remote. When we put the concave lens close to the convex lens, its effect will be to throw these images farther away from the lens, so that the effect on the violet images will be stronger than on the red images, and by a proper correction of the lenses the final violet image can be made to coincide with the final red image.

If the same kind of glass were used for both lenses, in order that the dispersion caused by one might be neutralised by the other, the curves would have to be such that the deviation of one would destroy the other, and therefore the pair would produce no image at all; but being able to use flint glass with a considerably higher dispersive power than crown, it is possible to destroy the dispersion without destroying the deviation.

The two lenses of an object glass are placed together for this reason. The pencils of light being incident on the first lens centrically, the greater the distance between the lenses, the more eccentric will be the rays on to the second lens; so the closer together the lenses are placed, the more advantageous the result.

With all optical systems (apochromatic systems excepted) the sharpness of the image projected is limited to one particular colour of the light transmitted, green-yellow in the case of lenses used for ocular observations and blue-violet in photographic systems, whilst the other rays give more or less confused images, appearing partly as colour fringes and partly as a general blur.

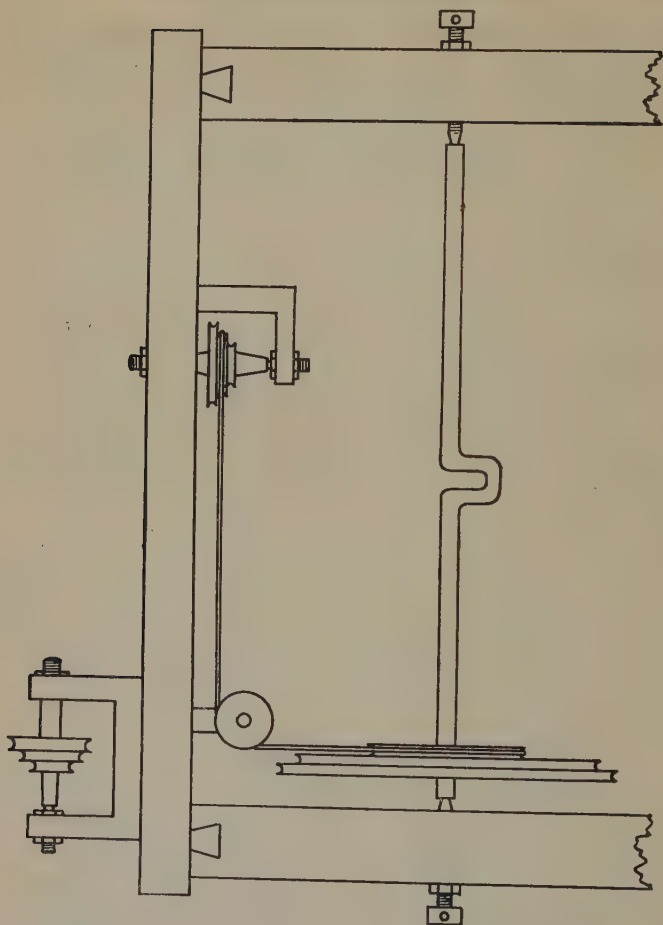


Fig. 11

Before proceeding farther, it will not be amiss to finish this introductory chapter by a sketch of a bench

an amateur will require if he intends to go thoroughly into the work. Of course, an ordinary lathe with an iron bed will do; but as so much water is used in the different processes, it very soon spoils the look of a good lathe. Besides, the iron bed is a source of danger to the lens-worker. You stand a chance of saving a lens if it should slip on a wood bed; but it is all over with it if it fall on an iron one. With most other materials it is possible to piece, solder, thicken, and lengthen; but in lens-work, once the glass is off, there is no way of putting it on again.

Fig. 11 is a sketch of a bench I put together for an amateur glass-worker. It consists of two old lathe-heads and a wheel and crank, and, having both a horizontal and vertical motion, will be found to be capable of doing any of the work described in the subsequent pages.

CHAPTER II

TOOLS USED BY LENS-WORKERS

THE tools used for lens-work are not very complicated. There is no elaborate machinery required. The result of the work mainly depends on the skill of the workman, and it is very seldom you meet with two men who work exactly alike. I have known two men on similar lenses, using glass from the same sheet, whose work could be distinguished at a glance. And there was just as much difference in the look of the workmen's benches as in the work they produced. One bench was always clean and tidy : the tools were always nicely turned, squares cut on the small tools for a spanner to tighten them by ; but the other one's bench was always in confusion. He had no square on his *runners* to tighten them by ; he would sooner knock them up with one of his turning-tools. It generally happened that after a little use they ran out of centre, and he then had recourse to a piece of paper to *cant* the tool a bit true, which went whizzing round, making a little cyclone of dust to fill his fine emeries and putty. His hospital for incurables was always well filled with patients. Great care should be taken to have everything perfectly clean.

Tools for Slitting Glass. A description of some of the tools will form the subject of this chapter. The

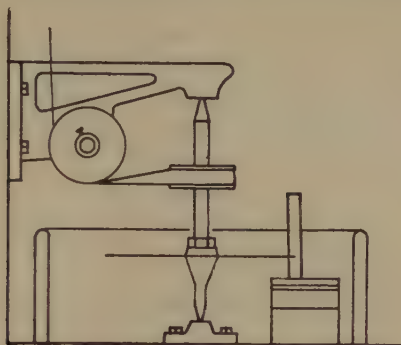


Fig. 12.

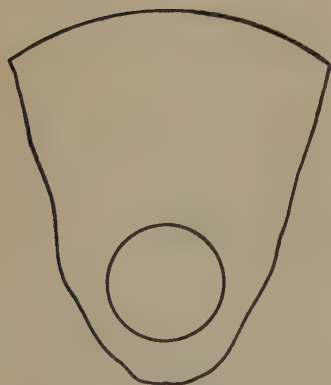


Fig. 13.

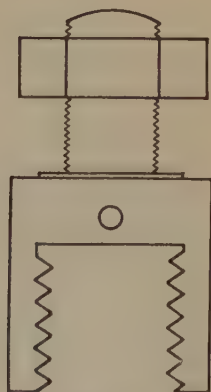


Fig. 14.

first tool that will claim our attention will be the slitting machine, as it is the first used after choosing the

glass (which will be referred to later). This tool will save its cost over and over again in the course of a year. Fig. 12 is a machine that is always kept ready for this work ; but one can easily be made that will go on our vertical lathe-head. Get a piece of very thin sheet iron 12 ins. diameter, and when cut round with a pair of shears, get the centre, and cut a hole in it as

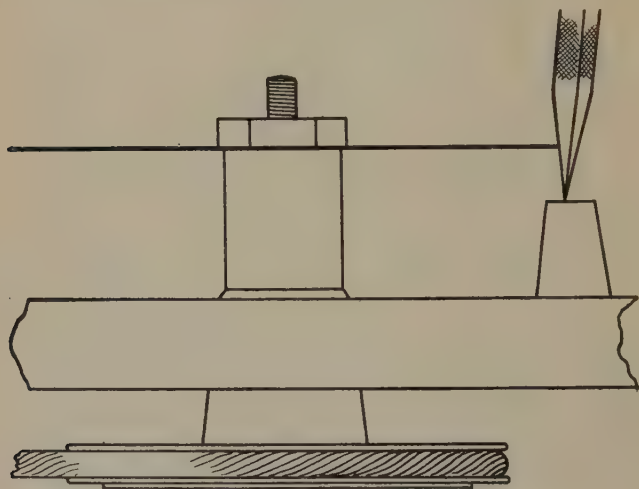


Fig. 15.

Fig. 13. Now get a *chuck*, and turn it like Fig. 14, and screw a nut on it so that it clamps the thin iron disc. Now we can put it on the vertical head and turn it true ; that can be done by holding a sharpened three-square file to the edge whilst revolving, having a block of wood to rest the point of the file on, like Fig. 15.

Interchangeable Chucks. It would be best to get an interchangeable *chuck* for the lathe that will take a gas thread. The union pieces can be bought for a low price, and we could have used two for our slitting disc, and they are always handy for making up runners. To use the slitter we shall require some paraffin oil and diamond dust. The diamond splinters you can

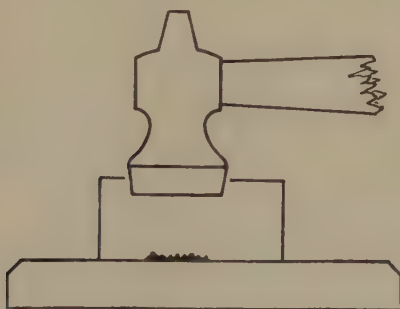


Fig. 16.

buy at so much a carat from a diamond cutter or occasionally from a jeweller. To smash the diamond splinters to dust, get a piece of flat iron, put the splinters to be pulverised on it mixed with a little oil, put a piece of tube round to catch the pieces that fly, and give the splinters a few sharp taps with a hammer (Fig. 16) till it is all in powder.

Method of Charging Slitter. To charge the slitter, get a little of the powder and oil on the tip of the finger, and touch the edge of the disc whilst revolving, holding the glass to be slit at the opposite side of the

disc; this will press the diamond dust into the soft iron. Fig. 17 will show the process. Whilst splitting keep the disc well lubricated with the paraffin oil above and below, or it will get hot and break the glass, or *buckle* the slit. A zinc box will have to be made to catch the glass, dust, and oil that flies off, for it makes a mess difficult to clean up.

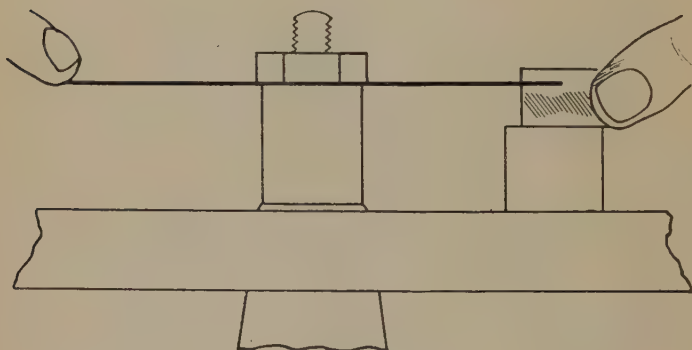


Fig. 17.

True Tools. *Chucks* are used for raising or lowering the work when you want an alteration of the figure without altering the polisher; these are known by the name of *short or tall boys*, and are shown in Figs. 18 and 19. We can use the gas unions to advantage for this, for we can get almost any height with them. The true tools for grinding can be made of either brass or iron, but brass is best, as it can be more easily turned. The shallow tools are made in a small part

of a semicircle, and are always used horizontally. The deeper the curves the less metal they take, so we

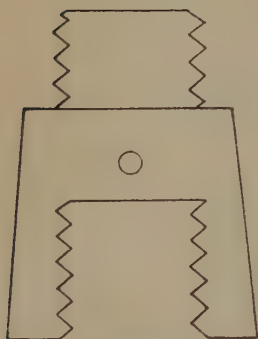


Fig. 18.

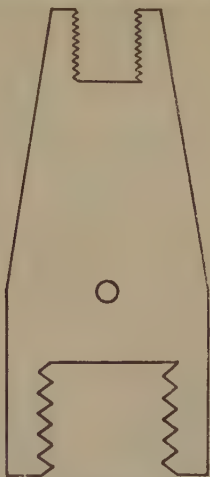


Fig. 19.



Fig. 20.

give them a greater part of the semicircle, and they can be used either horizontally or vertically. Figs.

20 and 21 show the shallow and deep tools respectively.

Roughing Tools and Runners. The tools for the *roughing* processes are always made of iron, and for

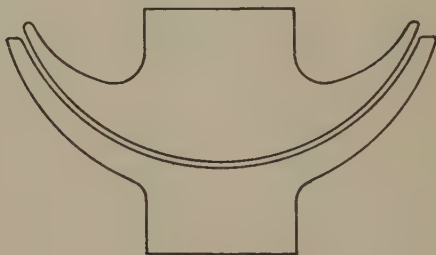


Fig. 21.

the concave surfaces should be a little deep to the curves, and shallow for the convex. Runners to fasten the lenses on can be made of pewter, and the gas

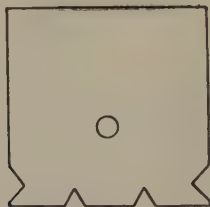


Fig. 22.

unions can be used again; they can be turned as in Fig. 22, with a recess round the end, and one or two V's filed on the edges. A mould can be made on to the

true tool, the union laid on it, and the melted lead or pewter poured round. The shrinkage of the metal whilst cooling will hold very tight. These *runners* are easily made and turned or altered, so you never need let your lens “give” for the sake of making a suitable runner.

Gauges. Fig. 23 is a piece of a float or rasp, and is used for knocking the edges off deep convex lenses to

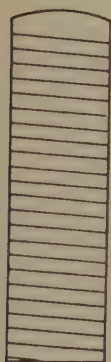


Fig. 23.



Fig. 24.



Fig. 25.

save grinding,—a risky tool at its best. Fig. 24 is called a *knocker-off*; this is made of boxwood, and is used for parting the lens from its pitch mallet. When the lens is quite cold, a sharp blow on the pitch will generally start it, and it can be taken off. Care must be taken not to touch the glass, or a shatter will be the result. Fig. 25 is a key used for undoing the

chucks. These should always be used for a runner that may have got jammed, and cannot be undone without knocking; for a knock, especially in cold weather, will be sure to start the lens. Fig. 26 is a round and hollow gauge; the round gauge is first made to the

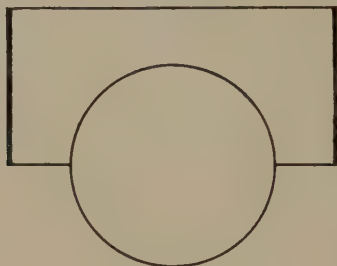


Fig. 26.

slide gauge, and the hollow one to the round. It is always best to have both a round and a hollow gauge for deep work; but for shallow work a segment can be used. To save metal the gauge is generally made to two curves, as Fig. 27.



Fig. 27.

Caliper and Step Gauges. A tool used very much for gauging the thickness of concave lenses is a pair of double calipers (Fig. 28), used in conjunction with a substance or step gauge (Fig. 29). These *step gauges* are kept in series of every $\frac{1}{100}$ in. between the steps.

These two tools are mostly used in the roughing processes. The final measuring is done with sliding caliper

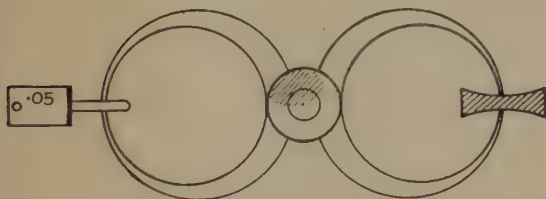


Fig. 28.

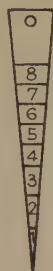


Fig. 29.

gauges or dial gauges, which will be described later on.

Importance of Length of Holder. Different sorts of handles are used for heating, blocking, and polishing. Figs. 30 and 31 will show the form required for large

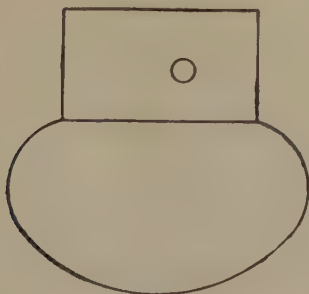


Fig. 30.

work. A good deal depends on the handles being a suitable length to the curve being worked; for if a

handle is too long or too short, the lens is liable to *cant* from its curve and *jump*.

For very small work it is almost impossible to get true spherical surfaces unless the length of the holder is taken into consideration. I had a set of eighteen with a difference of just over $\frac{1}{10}$ in. between each, and

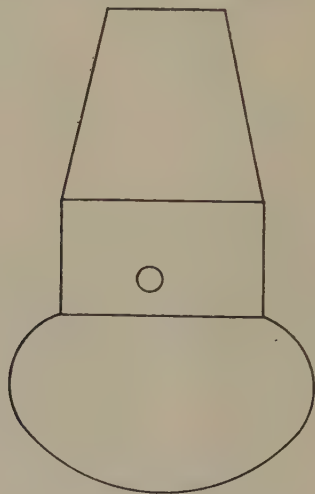


Fig. 31.

for working a front lens for a homogeneous system $\cdot 018$ radius, three hundredths and six thousandths of an inch diameter, the best results were obtained with a holder $1\frac{1}{10}$ in. long. A longer handle would have a tendency to cause a *pip* on the lens. You can imagine what a small lens it is by the figures; but it required just as much figuring as a telescope objective.

CHAPTER III

TOOLS (*continued*); INSTRUMENTS USED FOR TESTING LARGE
LENSES

To continue the list of tools used in lens-work, those mentioned are the general ones, and comprise all the tools a finisher requires. The computation being perfected, the glass is given to the foreman, who proceeds to cut it, if in sheet, to a size somewhat larger than required, and it is examined for any imperfections; if discs, they all have facets, or small windows, worked on the edge for examination. The imperfections looked for are *air-bubbles*, *feathers*—that is, a series of small bubbles that look very much like a feather, which are caused by the too rapid cooling of the metal—*veins*, foreign specks, and *dead metal*, or parts of the ingredients that have not become thoroughly mixed. If pretty clear, the glass is ready for the *rougher*, who is given a drawing with the diameter and substance to be left.

Process of Working a System. We shall suppose that the lens is to be of the rectilinear or symmetrical type, and is to be a meniscus. If it is cut from the sheet, it will require to be shanked round—that is, the edge gradually nibbled away till it is the required

size by means of a pair of very soft iron nippers. Now comes the "tool" described in the previous chapter (Fig. 23). This is used to save time by chipping the edge of the lens away before starting to rough it to curves. The tool is all very well in its way, but very risky at the best. It is just as liable to knock a splinter in as knock one off. The piece of glass is held by the edge, and the rasp, or float (*flonk* is the name generally



Fig. 32

given it by its users), is held at a certain angle and struck against the lens, letting it run down from tooth to tooth. The angle at which it is held has a great deal to do with its efficiency; if the proper angle is not got, it will shatter in. Fig. 32 will show how it is used, but my advice is: Let it alone, for the sake of half an hour's grinding.

Roughing. The rougher gets the nearest roughing

tool to the curve wanted, and proceeds to grind the lens to shape. The deep side is done on the lathe, the tool running in a *catcher*—that is, a wooden box to catch the emery that flies from the tool during the processes of roughing; as this is used over and over again, it forms the basis from which all the fine emery is got. The convex side is ground near the curve, and the concave side partially roughed out (Fig. 33). Then come the true tools, a pair like Fig. 21 for the convex surface and like Fig. 20 for the concave. The lens is now got to its proper curves by different grades of emery till it is to the fineness required, and is gauged



Fig. 33.

from time to time by means of the double calipers for substance.

Smoothing. When left from the rougher's hands the lens should be to the *substance* (the rougher's substance is generally one or two hundredths over what it is required to be when finished), and the surfaces should be free from holes and scratches, and when held to the light should present a fine grey and perfectly homogeneous surface, the edge free from splinters and perfectly sharp. It now goes to the finisher, and if very particular as regards figure, it is put on a *block* to continue the curve, or on a pitch *mallet*, which is in

turn stuck on to a runner. The deep side is the first smoothed or ground. This is accomplished by the use of three or four different emeries, gauging the tools to see they are quite to the curves. When perfectly smooth and quite free from all marks and scratches, the lens is polished. If on a block, the lens is warmed off, and if on a pitch mallet, when perfectly cold started by a blow with the *knocker-*

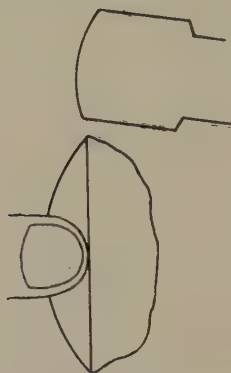


Fig. 34.

off (Fig. 24), which is used as in Fig. 34. The shallow sides are either done in blocks (which will be described), rings, or circular pieces. In the polishing the lengthening *chucks* are used, and the different handles are all the tools the ordinary glass-worker requires.

Edging. When the lens is cleaned, soaked free from the pitch or wax it has been held by, it has

another gauging, and then it goes to the edger. If a large lens, it is stuck on a pitch ring, and gradually pushed true by the fingers. It is edged by means of an inclined plane, like Fig. 35, which has a disc of copper for the cutter; and the emery is pushed between the glass and the copper by a little wooden shovel. The smaller lenses are edged on *ring-chucks*

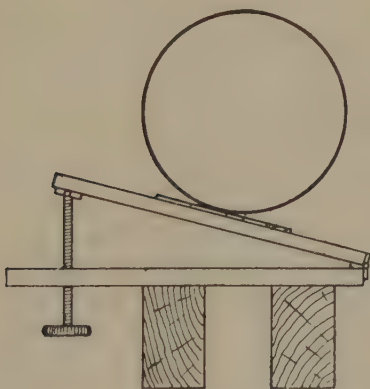


Fig. 35.

with a copper slip, or turned down with a scraper. The lenses of a pair or triple are cleaned and balsamed. This is done by heat beneath a brass plate, by placing a small quantity of balsam between the surfaces, and gradually working out as the heat increases, as much as possible without it starring, by means of a cork. This is the balsamer's only tool beyond his heating-plate and gas stove. The lenses have now to be

centred, and are stuck on a ring-chuck, and the flint

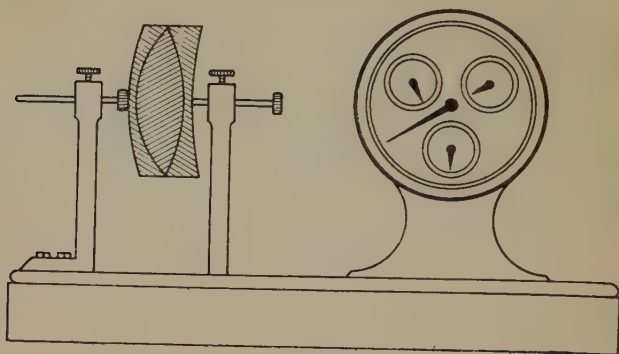


Fig. 36.

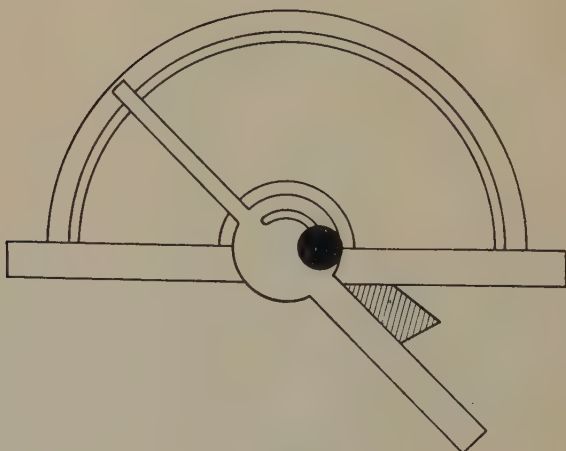


Fig. 37.

set true by its edges; the other lens or lenses are set

true by their surfaces. The lens is now ready to be

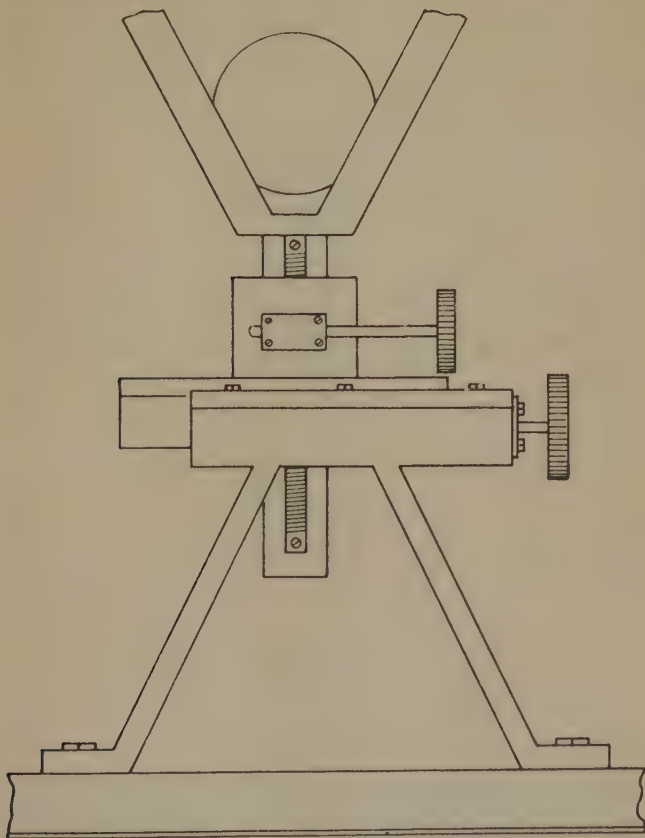


Fig. 38.

tested; but this is done in a room from which the

workmen are generally excluded. Then they are gauged together by a dial gauge. Fig. 36 shows one I made some years ago. You could see at a glance the exact reading—inches, tenths, hundredths, and thousandths, each on its own dial. The jaws were adjust-

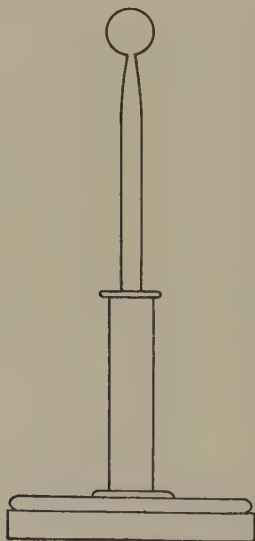


Fig. 39.

able, so as to enable one to gauge the deepest curves. Fig. 37 is an instrument I made about the same time for gauging plano tools and prisms. The lenses are now put on the testing instrument (Figs. 38 and 39), and if correct they are put in their cells.

Testing. For microscope work, much smaller tools are required, and in place of the *horse* the microscope is used for "testing." This is a most important part of the optician's business, and will claim one or two chapters to itself.

It may be mentioned here that the figure of a lens is now most accurately tested by means of a contact gauge, which is made of very hard glass to the opposite curve. When this is laid on the lens, perfect contact, and therefore an exact curve, is indicated by the appearance of interference colours, on the principle of Newton's rings. Of late years special forms of interferometer have been used to measure the aberrations of lenses, prisms, etc.

CHAPTER IV

PITCH AND HOLDING MEDIUMS USED IN LENS-WORK

THIS chapter will be devoted to the different mediums for holding the glass whilst being worked, and the general way to work shallow surfaces and blocks. On the different mediums for holding the glass much of the final success depends; and they should be carefully prepared, and kept free from dust and grit. The smaller lenses are stuck on to holders by shellac or black wax, the larger lenses on to pitch mallets; and the large lenses, from 3ins. upwards, if worked singly, are held by small pitch pellets. The following are the general directions for making the different holding mediums:—For pitch, always get the barrel pitch (Stockholm); never have the stuff sold in pound boxes. You can always tell the best by its brownish colour and the prismatic colours it shows when freshly broken.

Making Pitch for the Work. The raw pitch requires to be hardened, as it is much too soft for use, and the lenses would sink with the least friction. I always found it best made as follows:—Get 2lb. of best Stockholm pitch, and boil for some minutes in an ordinary iron cauldron; then get $\frac{1}{2}$ lb. of finely sifted wood

ash, free from foreign substances, and stir in, keeping it just bubbling; then add a small lump of tallow. This pitch should now be hard enough to stand a good pressure; but it can be made harder by adding more wood ash, if required. Other materials are used for hardening, such as yellow ochre or plaster of Paris; but the one given above is the best to use, as it is not so liable to contain grit to mark the surfaces, and the tallow being mixed with it, the lens will part from the mallet easily. It is less liable also to pull pieces out of the lens, should it be necessary to leave it all night, for with some glass the expansion will sometimes cause the lens to fly off some distance. If the pitch were hard-holding, it would pull pieces out of the surface, and so spoil the disc.

Parting the Lenses from the Pitch. When a block or lens is finished, it will generally be sufficient to put the glass under a tap of cold water; the lenses will then part from their mallets, and can be taken off: so with good pitch even the risk of breakage with the knocker-off is obviated. In the case of large lenses, to save the risk of flawing by the expansion of the holder, the lenses are put on small pellets; and even then I have known a large lens (which had to be reworked) show distinctly the little circles of twenty-four pellets on its surface, as if the parts of the lens where it rested on the pellets were pushed in. A good holding medium for edging lenses from 1in. to 2½ins. is made of Stockholm pitch and resin (white)—two of pitch to one of resin—boil up together, and roll out in sticks. This sets very

quick, and when the lens is finished will start with a slight blow.

Mediums more Tenacious than Pitch. A wax for holding small lenses is made as follows :—Get some best orange shellac, and lower it down with an essential oil. Cloves I generally use. For edging small lenses, a more tenacious holding medium is required than the pitch and resin, and this is made of best orange shellac blackened with finely sifted vegetable black and made soft with oil of cassia. This medium is also very good to stick small lenses on with, for, being jet black, you can see the surface of the lens better. When commencing, it is a very good plan to stick all flints on with black wax, and all crowns on with shellac, so there should be no fear of mixing them before they are turned. It is better to make the wax oneself than to trust to shop wax, for it is very gritty stuff at the best, and the least particle that gets between the lens and the edging chuck means a mark on the surface. So much for the pitches, etc. They do not form a very formidable item of outlay, but they must be good and kept clean, or bad work is the result.

Blocking Lenses. Blocking is an important part of the manipulation, and has much to do with the final success, so I will describe the general principles when more than one lens is to be ground at the same time. To facilitate this, it is the simplest way to stick them on pieces of pitch, so that it does not matter how irregular the opposite side or shape is, they can be got down to the curve with little trouble, and are easily

fixed, no matter the number, by heating a shell near the curve and laying it on the pitch mallets when the lenses are arranged as wanted.

Malleting. Suppose we want to work several lenses to a shallow curve. After they are ground up, they are placed on a warm plate, and a lump of pitch on a short stick heated to the consistency of dough. With the finger press the pitch to a point, and put it on one of the pieces of glass on the warm plate, lifting it up by that means, and work and press it about till the lens appears black all over—that is, when all the bubbles



Fig. 40.

of air that might be in the pitch, or between the surfaces, are pressed out; get the pitch well up to the extreme edge of the lens; then cut off a sufficient quantity to make the round of the mallet the height of half the diameter. When left ready for blocking, the arrangement should be like Fig. 40. Care should be taken to get the mallets all one height, or the block will get confused.

Arranging the Block. Supposing the lenses to be all malleted, the next thing is to arrange them as symmetrically as possible on the true tool, rubbing them

down one by one with a little fine emery, and arrange them, if seven, one in the centre and six round, like Fig. 41. The more symmetrically the block is arranged, the more perfect will be the figure in polishing. If the number falls short to arrange symmetrically, one or two dummies should be put in, care being taken that they are the same glass, or they had better have been left out, for different kinds of glass take different times

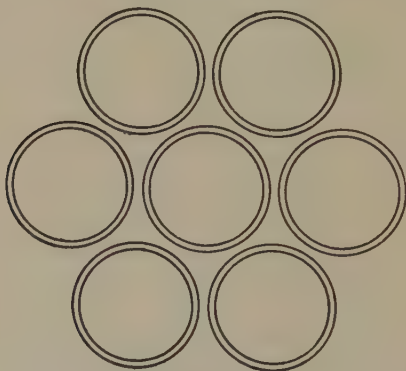


Fig. 41.

to polish, and a piece of hard crown, for instance, put with a block of flints will upset a block altogether. When arranged to satisfaction, a runner should be heated, and care taken to heat it *levelly* all over; for if one side is hotter than the other, it will cause them to be one-sided, and then the lenses would have to be remalleted. The heat of the runner can be tested by pressing a small piece of pitch on it; if it should just

run, it is the heat required. Now put it on the mallets in the tool (Fig. 42), pressing down slightly till you think the lenses are held enough; then cool with a wet sponge. The block can now be lifted up and examined; and as it is still quite warm, you can push any lens that may have moved to its place again. A little fine emery may be placed on the tool, and the block worked over it. When you lift the block again, ex-

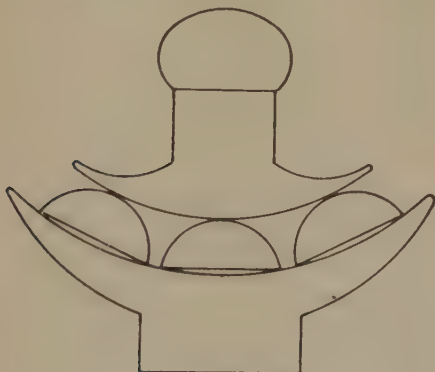


Fig. 42.

amine the impressions on the tool, and if the lenses are not all down, the block should be warmed again until the impressions on the tool are distinct.

Piecing a Block. If the runner has been heated properly, and the mallets are all one height, the block should be perfectly true. We have been treating a block supposed to be of a number that will make a block pretty full. If we look at Fig. 41, we see that

the polishers would not lap overmuch, for they go too close together. Now, if we have to work a block, and the lenses are of a size that will only allow four to be worked (Fig. 43), we put them as close as we can; but there is a large space in the centre and between the edges. Now to get a true surface is almost impossible; the polisher has too great a tendency to round the edges, and however careful a man may be, the edges

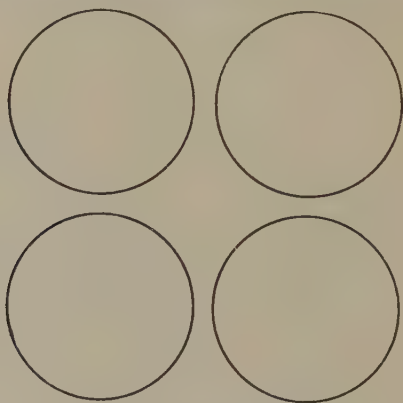


Fig. 43.

are sure to round, and the rounding must be edged off, so consequently there is a waste of glass—and $\frac{1}{4}$ in. means a lot more expense; so it is a rule in good work to fill the spaces up as Fig. 44. Now we have a block that it is almost impossible to round, and if the polisher is made right, a true surface can be obtained up to the edge. This rounding of the edge is a serious matter, so it is advisable, whenever working a

single shallow surface, to use circular pieces for all

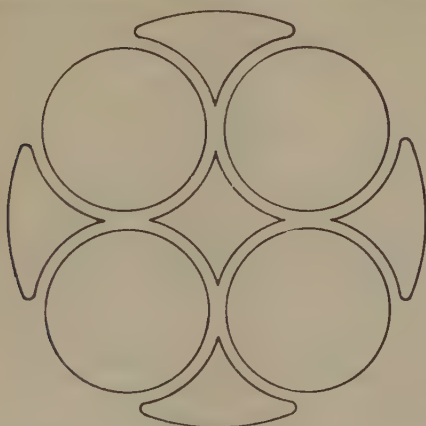


Fig. 44.

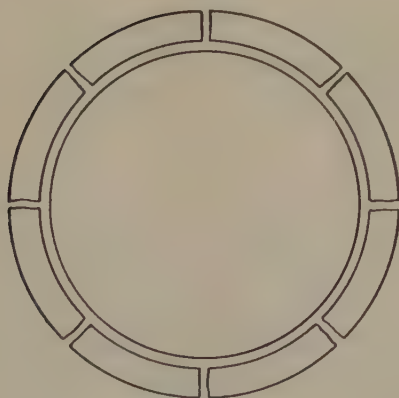


Fig. 45.

large lenses, rings of glass for the smaller sizes, and

moulds for thin lenses. Fig. 45 will show a large lens with circular pieces, and Fig. 46 in a ring. In the chapter on suitable glass those of comparatively the

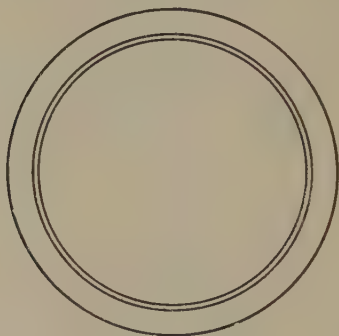


Fig. 46.

same hardness will be marked, so that often the filling-up pieces can be made of inexpensive glass, which works about the same as the lens being made.

CHAPTER V

DIFFERENT SYSTEMS OF LENSES

THE tools holding pitches, etc., have been described. The polishers had better be left till we are ready to use them, as they can then be explained as each comes into



Fig. 47.

use; so we shall give the different systems of lenses that have been found best to satisfy the requirements for the different kinds of work needed.

Systems of Lenses. Photographic lenses: Fig. 47, a system for a rapid symmetrical; Fig. 48, a system for an ordinary rectilinear; Fig. 49, single landscape system; Fig. 50, wide-angle doublet system; Fig. 51,

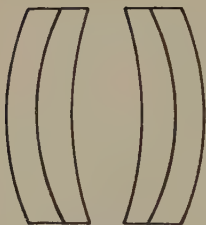


Fig. 48.



Fig. 49.



Fig. 50.



Fig. 51.



Fig. 52.

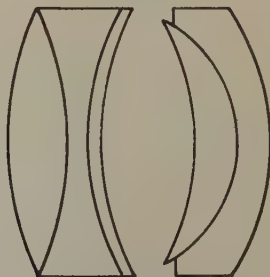


Fig. 53.

the Ross concentric system ; Fig. 52, the Zeiss anastigmat system ; Fig. 53, Zeiss anastigmat system ; Fig.

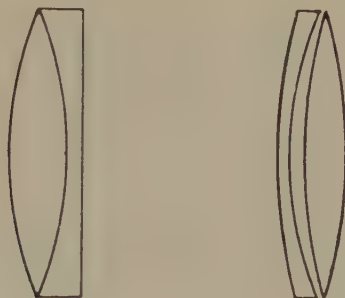


Fig. 54.

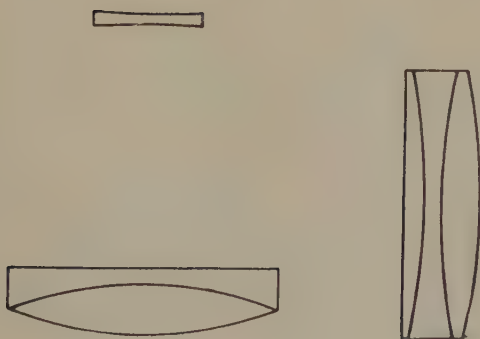


Fig. 55.

Fig. 56.

54, portrait combination ; Fig. 55, lenses required for one body of a common opera-glass ; Fig. 56, triple

combination for opera or small telescopes of better quality. Microscope systems: Fig. 57, triple combina-

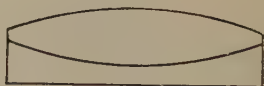


Fig. 57.



Fig. 58.

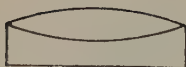


Fig. 59.



Fig. 60.

tion of low power; Figs. 58 and 59, doublet pairs for low powers from 20° to 30° of aperture; Fig. 60, combi-

nation for angle to 50° of aperture; Fig. 61, combination for systems to 80° ; Fig. 62, combination for

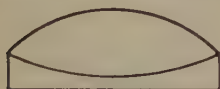


Fig. 61.



Fig. 62.

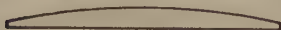


Fig. 63.

systems to 90° ; Fig. 63, combination for system to work with water to 110° of aperture; Fig. 64, com-

combination for system to work with oil to 130° ; Fig. 65, combination for system of high aperture, showing the

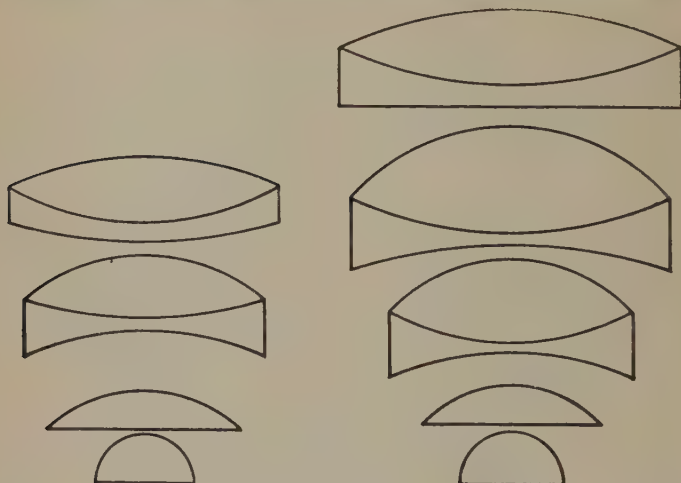


Fig. 64.

Fig. 65.

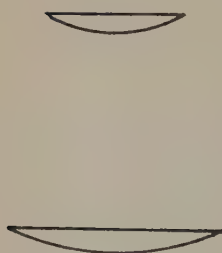


Fig. 66.

Fig. 67.

necessary lenses required to correct for all zones of the

objective; Fig. 66 shows the lenses for an ordinary Huygenian eyepiece; Fig. 67, the lenses for an achromatic eyepiece; Figs. 68 and 69, two forms of con-



Fig. 68.

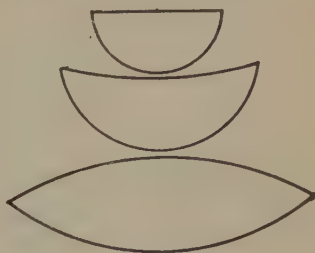


Fig. 69.

densers All these systems are drawn to scale, and some will be referred to in the subsequent chapters.

CHAPTER VI

THE POST ; WASHING EMERY ; WORKING DATA FOR 6IN.
RECTILINEAR

A Photographic System. It is almost time we got to work on a lens of some sort, so before going into the more advanced parts of the business we will try our hand at a photographic lens, a half-plate lens of the rectilinear or symmetrical type, similar to Fig. 48, but of different curvature. This is inferior to an anastigmat, yet is capable of doing some very good work. We have our lathe with a main chuck running horizontally, and if we have not the vertical arrangement, we can easily make a post of two pieces of stout tube, one fitting into the other, the smaller or inner tube being screwed into a stout plate that can be in turn screwed on to the bench, as Fig. 70, and the larger or outer tube with a screw on the top to take the tools and runners ; this sliding over the smaller tube can be turned round by the hand as the work requires it.

The Gauges and Glass. The first thing to be done is to make a set of gauges for the lens ; the back and front combination being exactly alike, only three gauges will be required, so we can set to work and make the gauges either out of a piece of zinc or sheet

brass to the following radii: 1.17, .54, and 1.46. Fig. 71 will give the exact diameters, and if these be measured by those who do not possess a slide gauge, will be found quite near enough to get good results. The working drawing will be as Fig. 72. The glass

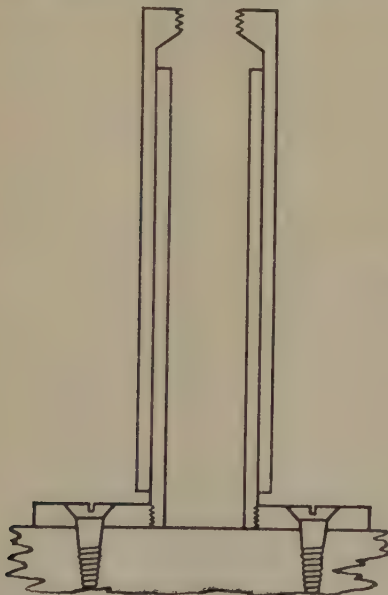


Fig. 70.

the curves are best suited to is a dense and light flint of the Jena glass, but Chance's heavy and light flints will be found to be pretty near, and if used there will be but slight difference at the finish. We only want a small part of the curve, as we are only going to work

this system singly, so we can make a pair of tools to the shallowest curve (Fig. 73) of the lens. If we turn them up as near as we can to the 1·46 gauge, we can grind them together with a little emery and water, getting them exactly up to the curves. Now, if we

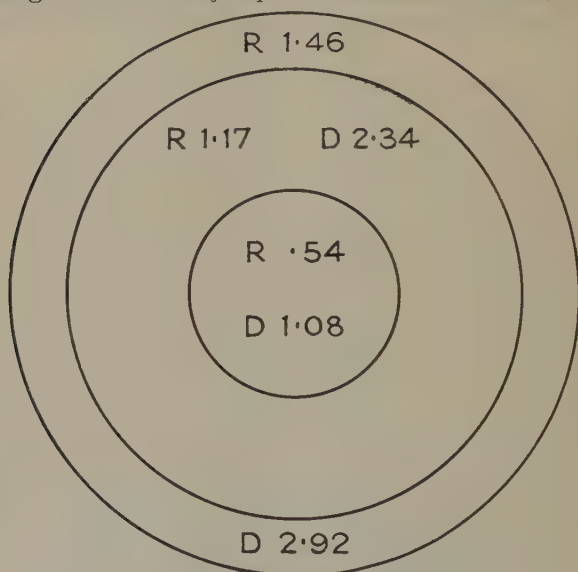


Fig. 71.

have our light flint—or, as we shall call it, the crown—it would not do to turn the shallow curve out, so we make it warm and put a small mallet of pitch to hold it by, and grind the curves out on the convex tool. After we have roughed them out, the next thing to be done is to smooth them; but first rub the tools

together, putting one on the post or vertical lathe, and rub one over the other: you will get a better contact than if you ground them in the lathe. If the tools are to the gauge, fine-emery the lenses either on the lathe or on the post.

Washing Emery. The coarser grades of emery can be bought in bags of 7lbs. weight, with the hole marked

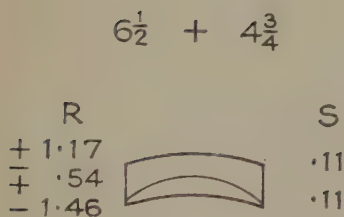


Fig. 72.

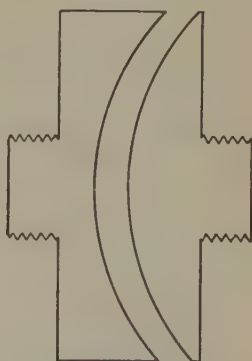


Fig. 73.

on it; that is, the mesh of the sieve through which it is put. But the finer grades are washed from the residue from roughing, etc. It can be bought, but is not to be always relied upon; but some very good emery is supplied by Oakey's, Westminster Bridge Road, London. If determined to wash it yourself, the best places to get the slush required for the emeries are at the glass bottle stopper grinders', who have no use for the emeries they have once used, so they can always be bought for a few shillings per hundredweight. Put the slush in a pan

half full of water, and break up all the lumps that may have formed, and put it through a sieve of about 120 holes to the inch ; the wire gauze will not cost much per foot, and can be stretched over a wooden ring and tied round. Sift the emery and part it—that is, stir it well up and pour almost immediately into another pan. By this means we shall have all the coarsest emery in the first pan ; this we can put on one side for grinding tools, etc. Now part again, first with seven seconds between the stirring and pouring and then with fourteen seconds. These two emeries will be fine truing for grinding out the turning holes, etc., in the lenses. Amongst the finer emery that is left in the pan will be a quantity of foreign substances termed mud, emery too fine to cut, powdered glass, etc., which must be taken away so as to get the emery as pure as possible. This can be done by stirring up the emery and water and vibrating the pan by knocking it with the closed fist and pouring off every ten minutes or so, using fresh water every time ; do not pour down too low, or the finest emery may go with the mud.

Very Fine Emery. Another way is to let the tap dribble on it, stirring it up every now and then, and the mud will float off. When the water seems pretty clear after being allowed to settle a few minutes, we can make a finer sieve ; fine muslin or cambric should be tied round the sieve we have used before ; be careful it is quite clean, and all the emery in the pan should be put through ; do not force it, but knock it gently through. Now part it again three or four times, allow-

ing a longer time—from one to ten minutes—between each pour. It is not the finest-looking or feeling emery that puts the smoothest surface on a lens, but a well-parted one (*i.e.*, one with a homogeneous grain)—one which will be to the feel sharper than many emeries that look and feel finer, but having more perfect grain, will work down cleaner and farther than a finer emery that is not so well parted, which will drag owing to having different grains among the emery working on the tool. The emery, when placed in pots, should be numbered according to the pour, and kept covered.

Truing the Curve. When the convex tool is running on the lathe, we put a little of the third or fourth emery (it is assumed that the two surfaces are free from holes and scratches) on the tool, letting the lathe turn slowly, and with the tip of the index finger move the emery from the centre of the tool all over; the feel will tell if there is the least bit of grit or foreign particle on the tool, which will cling to the finger. When the emery seems smooth and is pretty level all over, breathe hard on the glass to cover it with a slight moisture, and place it on the tool. Of course it is a shallow surface we are working for the size of glass, so we must work very slowly, almost as slowly as we can keep the lathe in motion. If we emery it on the post, which can be done, it takes rather too long to work down fine, and we never get the same surface as on the lathe.

Giving it the Final Emery. The lens is placed on the tool in the centre, the lathe revolving slowly. Now

work from the centre to the opposite edge of the tool, and turn the lens every time it gets to the centre again. The emery should be kept moist, but not too moist, and it should not be allowed to get too dry, but about that which can be kept by breathing very hard on it, with now and then a little sprinkle of saliva. As it works down fine the emery will turn black, and when the lens is taken off the tool both the lens and the tool should be of a blackish hue, and when the finest emery is worked down they should both be perfectly black. Of course, to do this requires a good amount of practice.

Making the Polisher. Now, we suppose we have got our shallow sides emiered to satisfaction; we must proceed to polish them. We can polish them either on cashmere, silk, white wax, or paper. As both silk and cashmere are similar, with the exception that silk gives a rather better surface, we will describe those first. Get the convex tool that we have just ground our surfaces on and put it on the post or vertical lathe, having a check on the latter to stop it revolving. Now get some *tacky* (pitch run down to the consistency of treacle by the aid of turps), and with the tip of the finger daub the centre of the tool, or rather make an oval of *tacky* in the centre. Get a piece of silk or cashmere, and cut it slightly wider than the glass and three times as long, making it slightly narrower at the ends, and, nicely rounding it off, lay it in the centre of the tool and rub down with the fingers. It should be on the tool as Fig. 74. Now get some putty powder

(oxide of tin sold in $\frac{1}{4}$ lb. packet at 6*d.*), and rub a little in dry to fill up the material. Then put a little water

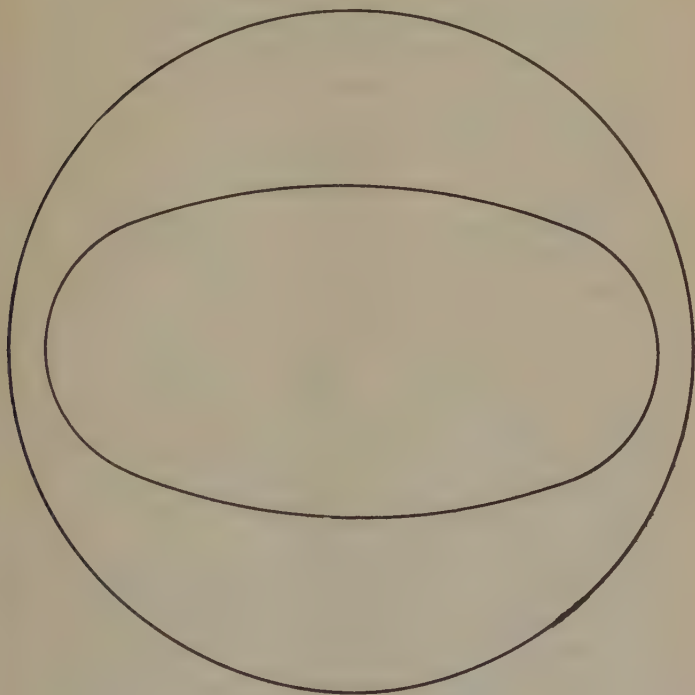


Fig. 74.

over it, and well rub in. Next get the lens, and after carefully wiping, lay it on the polisher, and hold it firmly down by the thumb and forefinger; then rub

it across from end to end, taking care to turn it every time it gets to each end.

Polishing. If the polisher is made as directed, the lens should polish slightly more in the centres than the edges, which is the best way it can for results. If the lens is decently emiered, it should polish in thirty minutes. Now for the wax. To make this polisher, you require a shell—that is, a thin tool to the same curve as the one we have been working on, with a series of recesses in it undercut to hold the wax on. Now get some paraffin wax, and mix almost as much putty as it will take up; then pour a layer on the shell, first putting a ring of paper round it to prevent it running off. When it is cool, you can turn it to the curve, touching it with the opposite tool, and wherever it touches it will leave a black mark, which can be skimmed off till it touches all over. When it is to the curve a few lines can be turned in it, and you can proceed the same as with the silk, only working all over the polisher and drying up the water and putty towards the finish. If we polish it with paper, we shall proceed like this:—Get a piece of thick cartridge paper half as large again as the glass in diameter. Get a teaspoonful of starch; mix with a little cold water till it is rather thicker than cream; pour boiling water upon it, and stir quickly; then rub a little over the centre of the tool, lay the paper on, and press down with the opposite tool. When dry, rub a little rouge on with a piece of tissue-paper, rubbing as much as you can off; then proceed to polish, first across and

then with a circular stroke ; three lots of rouge will be sufficient to polish a surface. To get a successful surface, it is essential that the edge of the curves should be very sharp (as left from the shanks) ; if it is chamfered or turned, it is very liable to sleek, but if left from the shanks, it seems to clear the polisher itself.

CHAPTER VII

WORKING THE SHALLOW SURFACES OF THE SYSTEM

THE two shallow surfaces being completed for the crowns, the next to be done is to grind the shallow convex surface of the other two lenses—the flints we shall call them—to the 1·17 curve, altering the tools that we have used for the first two surfaces to the new

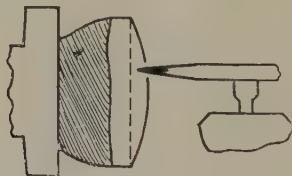


Fig. 75.

curve. Mallet them as in the crowns, and emery up to the curve. That can be done exactly the same as described in the last chapter, but we must polish them differently.

Setting the Convex Surface True. After the two surfaces have been fine-emeried, the next thing is to turn a runner, about the same size as the lens, with a flat top. Now make this runner warm, and run the glass and mallet true on to it, as in Fig. 75. When

cold they can be laid aside whilst we make the polisher. Get a small runner and turn it roughly to the curve, having it about the size that the glass is. Now make it warm and give it a coating of the pitch about $\frac{1}{10}$ in. in thickness, and whilst it is warm press it on to the convex tool that has been ground up to the curve. The pressure should mould the warm pitch perfectly to the curve; but when it gets cool it is bound to shrink a little, so we will get some rather coarse emery and grind it to the curve. When it is up (*i.e.*, to the curve), get a little tacky on the end of the finger, and put a slight coating all over till it is



Fig. 76.

stiff. Cut a circle of cashmere or silk rather larger than the runner, which should be like Fig. 76. Lay the polisher on the tool and press the prepared runner on to it, working it gradually over the tool till every part of the cashmere or silk touches the tool, which can be told by the discoloration.

Polishing the Surface. The glass and tool are now ready, so we can screw the former on the post or vertical lathe, and proceed to polish it, holding the polisher lightly by the thumb and forefinger, and how it would appear is shown by Fig. 77. The screw of the runner is apt to blister the fingers, so we can make a small

thimble to screw on for protection. The polish should take more in the middle, and if made properly will do so. Start with a circular stroke, never letting the polisher go over the glass more than half its diameter, working the polisher with the right hand, and turning the post with the left.

Polishing a Perfect Curve. If a composition polisher be used, that can be pressed to curve on the tool and

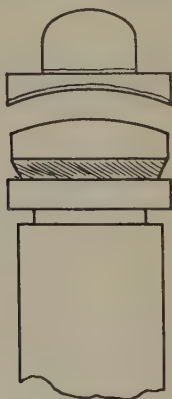


Fig. 77.

turn afterwards, and polish as with a cashmere one. It has been seen that I always make the polishers to take in the centre, and at the first thought it seems that I am intentionally polishing the lens away from the curve; but if we look further into the subject, we shall see that to get a true surface we must proceed as stated. In a series of experiments I carried out some years ago, I tried all kinds of polishers and methods of

polishing, carefully noting every effect the different methods had on a test image. I found that, where a surface had been polished seemingly level, it turned out very badly when tried with the steel balls, and a surface polished from the edge was useless for showing a perfect image, while all lenses polished from the centre invariably gave good results; so to the workmen it is always their aim to start polishing from the centre as levelly as they can. We have our lens on the post, and after charging the polisher, lay it on the glass and start polishing. After a few strokes the polisher gets harder to move. If we take it off and damp it, at the same time looking at the lens, the centre will be almost bright, and the edges grey; but after a time the edges seem to come up all at once, so that just before it is finished the edges are as bright as the middle, which by the start would be polished some time before the edge. So it is seen that the edges of the polisher, when in full work, must cut nearly twice as fast as the centre, and if we had started polishing levelly, it stands to reason that the curve when bright would have been totally different from what was intended.

CHAPTER VIII

MOUNTING DIAMONDS FOR TURNING; DIFFERENCE OF CUT WITH DIAMOND AND SCRAPER; SPOTTING, GAUGING, AND CENTRING.

HAVING finished the outside surfaces, we must get to the contacts or the surfaces that are to be cemented together. The first thing to be done is to make or alter two runners to nearly the outside curves, rather shallower for the convex holder and deeper for the concave



Fig. 78.



Fig. 79.

(Figs. 78 and 79); these must be turned up true, and a few runs turned in to hold the wax. Make the runners warm, put a layer of the prepared shellac, put the lenses on, pressing them down to the holder, run or

push them true, and let them cool. These will not be ground up, but turned, and we can do it two ways, by using diamond turning tools or old saw-files. To make the diamond turning tool, first we must have a splinter of diamond, and it should be examined with a magnifier to see which would be the best position to set it in.

Diamond Turning Tools. The best splinters are those which are larger at the base, and they should be set so that the smallest end should be the apex of the



Fig. 80.



Fig. 81.

tool. Get a piece of drawn steel wire of suitable size, and drill a hole down it about double the depth of the length of the diamond splinter, drilling a very small hole for a vent. Now place the diamond in the hole that is drilled, as in Fig. 80, and with a pair of pliers press over the ends of the cylinder of steel, closing the diamond splinter; rub a piece of borax on a slate to make a flux, and silver solder or braze the whole together. You can see when it is solid by the filling up of the small hole. If the vent had not been made, the

expansion of the borax under the heat would very likely push the diamond out, despite the shoulder of steel pressed round it. When cold you can file the steel and solder away till the point of the diamond shows, and it is ready for use by placing the steel in a handle, and when mounted nicely the diamond should show like Fig. 81.

Old Files for Turning. For the scrapers, get a few worn-out saw-files, and on a grindstone grind the teeth away till they are perfectly smooth, and the edges are very sharp; it is best to grind up half a dozen or so at once, but do not oilstone the edges, as the files cut better when left raw from the grindstone. When put in handles they are also ready for use. The crown is now ready to be turned, so we shall screw it on the lathe tightly. Now put the T-rest as close to the glass as you can without touching it, and having a saucer of turpentine with a small piece of sponge in it. Start the lathe slowly, holding the sponge in the left hand and resting the sharpened scraper on the T-rest at about the angle shown in Fig. 82, grasping the handle tightly so as to hold the scraper as rigid as you can, letting the right hand rest against the chest. Now just touch the glass with the sponge, and without moving the end of the scraper, gradually bring one of the cutting edges to the glass, and it will take off a few splinters from the parts that project most. Every time you take a new cut you must move the scraper so that it presents a new cutting edge, and lubricate with the sponge at the same time. If these

directions are followed, no one will have any difficulty in turning glass.

Turning up the Deep Surface. Of course the dust comes off slowly, but you can turn up three while you are grinding one up with emery. You must be careful to hold the scraper very rigid all the time, for it cuts at rather an acute angle, and if not held firm will be liable to be dragged down, and the result is a shatter in the glass at least, if it is not broken. We can see when we are near the curve, and try it with the concave tool (which should be turned and ground to the



Fig. 82.

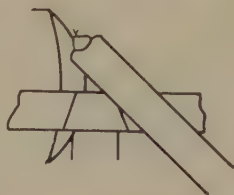


Fig. 83.

curve) by just putting it to the glass as it is revolving; and it will leave a circle wherever it touches, and you turn these black parts off till it is very near the curve. If a diamond be used now for turning it smoother, the speed of the lathe can be very much increased, and the diamond held as an ordinary turning tool, touching the glass lightly above the centre of the lens, as in Fig. 83, turning it till the tool seems to touch the lens all over, and then it is ready to be emiered. As the contacts must be worked together, we will turn up the flint; but we use a different tool for that work,

that being screwed on the lathe, and we get one or two flat 4in. pillar files ground up with a round nose. Turn the T-rest to the front of the lens and carefully turn out to the curve, using plenty of turps to lubricate it; but it is safest to use an arm-rest to hold the tool on, keeping the T-square as in Fig. 84. The round-nose tool will not be so liable to shatter in, and a truer curve can be turned; in fact, it is advisable to use the arm-rest in turning all inside curves, for if you can use yourself to one you will find it a great help for true turning. Fig. 85 shows it in use finishing off the curve.

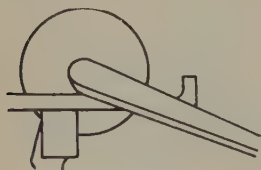


Fig. 84.



Fig. 85.

Spotting for Substance. If the crown is turned to the right size and left with a feather edge when finished, it will be to the right substance, but the flint must be tried. When turned up it should be warmed off its holder and tried with a pair of calipers and the substance gauge, and must be got nearly right before commencing to smooth it. The handiest way to do this is to have a tool very much deeper than the curve to be worked, running in the lathe; put some emery on it, and taking the glass with the thumb and forefinger, as in Fig. 86, grind a spot in the centre,

calipering it every now and then, till to the substance required. When right, put the glass on the runner and run it true by the aid of a dogwood peg.

Fine-emerying and Polishing the Deep Surfaces. The two lenses are now ready for grinding. Get the convex to nearly a sharp edge, grind the spot nearly out, and proceed to fine-emery. Before the final emery the tools had better be worked together and the lenses gauged; do this with the flint, as in Fig.

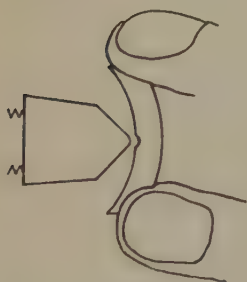


Fig. 86.

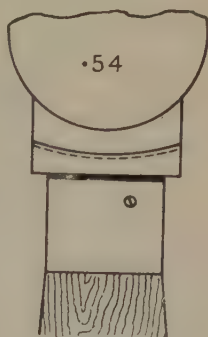


Fig. 87.

87, and to gauge the crown use the tool the same as if it were the flint lens. To make the polishers we can make the tools warm, and put a coating of shellac and a silk polisher, pressing it to the curve with the opposite tool whilst warm. When cold it can be cut round with a knife to the size required. If it is polishing level, or too much on the edge, reduce the polisher by taking a circle off till the lens polishes as desired.

If the composition be used, a runner can be turned to hold the wax with a run or two and some notches, and a piece of stout paper stuck round to form a mould, and the wax can be heated and poured in. When cold it can be turned to the curve, and the lenses polished. Do the same with the other pair, and the surfaces will all be done, and the lens ready for edging. To do this we require an edging chuck, which consists of a cylinder made from a runner or a piece of tube soldered on one the exact size the lens is to be left, with a small hole drilled at the side as an escape for the hot

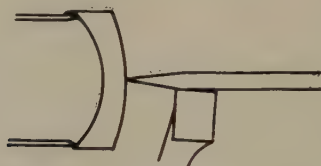


Fig. 88.

air, which would otherwise blow the lens off. If the chuck has been turned true, we can warm it and run a little wax round the edge, then warm the glass by passing it over the flame of a spirit-lamp, and press on the chuck the concave side to it, as it is easier to run up that way, as in Fig. 88. You can now sharpen the scrapers, and turn the lens carefully down to the size, and take off the chuck. The crowns will not want any edging.

Edging and Setting True. When the lenses are soaked off—that is, all the wax removed from them—

we can wipe them perfectly clean and balsam them. To do this, we must have an iron table that has a lamp under it to heat it. If the lenses are quite clean, get a drop of balsam on a peg and put a little on the centre of each crown. Now press the flints on them, and spread the balsam all over. Place on the hot plate, and let them bake for an hour. After that they should

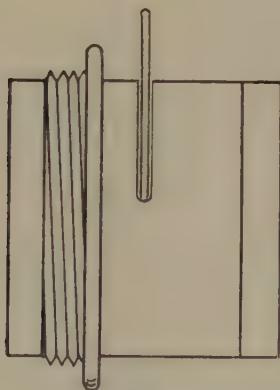


Fig. 89.

be quite hard, and are now ready for setting up. To do this, put the edging chuck on the lathe, turn true, and warm it for a slight coating of resin and pitch. Now warm the two lenses and press them on the pitch, the convex side to it. Run the flint true by its edge. Then hold the spirit-lamp in front of the pair, and let the crown get warm. When it just moves you can

gently run that true also; but be careful not to spin it out.

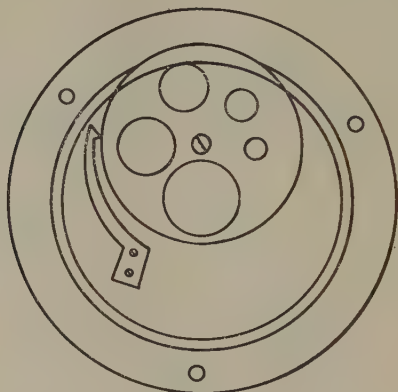


Fig. 90.

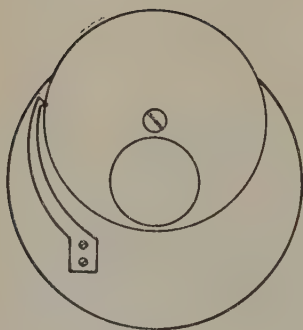


Fig. 91.

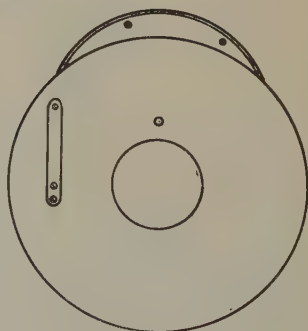


Fig. 92.

Chamfering. When cold the combination can be taken off by a slight blow on the side of the chuck, and

the pitch wiped off with turps. If we put the shallow concave tool in the lathe, and put a little emery in it, we can finish the two pairs off by putting a chamfer on the edge of the crown if determined to put a direct bevel on, or grind a little flat on the front if it is to be fixed with a ring, which will be explained while making the setting. Fig. 89 will give a general view of the setting when complete for a wheel diaphragm, and

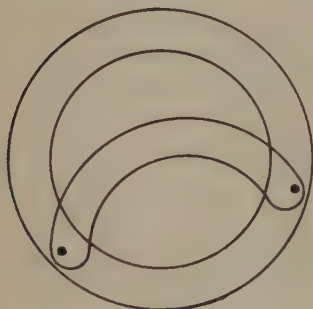


Fig. 93.

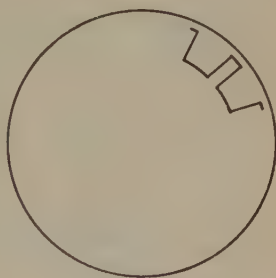


Fig. 94.

Fig. 90 the position of the wheel and front view of the setting with flange, without the cells. Figs. 91 and 92 show two ways of catching the wheel, and Figs. 93 and 94 show the parts required to make an iris diaphragm; but a very little difference is required in the body for either sort, only a shorter slot for the iris. The same casting can be used for either, the patterns for which will be described in the next chapter.

CHAPTER IX

MAKING PATTERNS; TURNING CELLS AND FITTING LENSES;
MAKING LEAVES FOR IRIS DIAPHRAGM

To start on the mount, we shall require, first, two pieces of boxwood $2\frac{1}{2}$ ins. in diameter to make the patterns for it. These can be screwed on the nose of

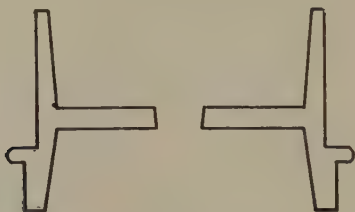


Fig. 95.



Fig. 96.

the lathe, and two patterns like Figs. 95 and 96. Get two like Fig. 96 cast, and one like Fig. 95, and you

can proceed to turn and mount up. First get a file and burr up the castings—that is, take all the rough parts off—then turn a boxwood chuck out so that the back of the casting for the body fits in, and drive it true. Now slide-rest the inside to 35 millimetres diameter, and cut a rather fine screw at the end; the depth of the body from the centre should be 23 millimetres.

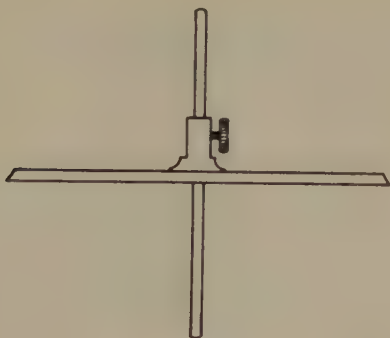


Fig. 97.

The Depthing Tool. To get this properly you will have to get a depthing gauge, or make one, which is a very simple job. Fig. 97 will show what it is. It consists of a piece of brass with a piece of drawn steel wire sliding up and down, so that it can be set to any depth and clamped by a small milled head. You can now slide-rest the outside of the setting along till you come to the shoulder; then knock it out of the boxwood chuck and make a brass one that will screw into

the body that you have just screwed ; make it fit well, as from this screw the truth of the mount depends. Now slide-rest the back out, getting it to a depth of 21 millimetres ; screw the inside to the chuck you are working with, so that the mount screws on either way. Now cut the main screw, the one that is to screw into the flange, and put a milling on the shoulder.

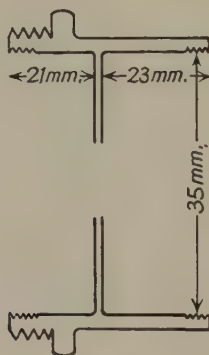


Fig. 98.

The Main Screw must be True. The body of the mount should appear as Fig. 98 ; this can now be put on one side whilst we make the cells. Turn a boxwood chuck out till you can secure the cell casting by the part that will be screwed, slide-rest out, and cut a screw inside both, and make a chuck to take them. When you have turned the fronts you can put a finish on the work by making a series of rings with a screw-tool—that is, hold the screw-tool on the T-

rest, and let each tooth cut a ring, and by moving the screw-tool from time to time you can cover the face all over, and they will be ready to be done the other side, and up to the present the cells should appear as Fig. 99. Now get the chuck you have screwed the cells to, and put it on the lathe. Put one of the cells on, and proceed to screw it to the body of the mount. Now you can carefully slide-rest the centre out, leaving a shoulder at the bottom for the pair of lenses to rest on. Be careful that the lenses fit perfectly, but not too tight. Now treat the other all the same, which

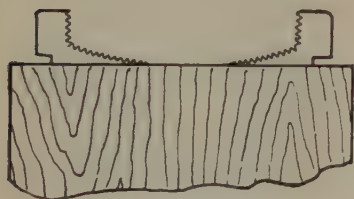


Fig. 99.



Fig. 100.

when finished should be like Fig. 100. This shows the lens in its place, and the sort of shoulder required. The body of the lens can now be slotted by means of a rather wide saw, to let the wheel diaphragm in, or the lever of the iris. If a wheel diaphragm be used, get a disc of metal 1 millimetre thick and 30 millimetres diameter; centre it, and you can either put a milling on it or turn it plain, for whichever way you may determine to stop it. Now just broach the centre out to slightly taper it. Get a piece of wire and make

a screw (it must fit the taper tight), and whilst it is on the screw you can slide-rest a slight cut off the back, so that it leaves a small boss on the centre of the diaphragm. The screw should be turned down to the same thickness as the diaphragm, and a screw made on the end somewhat smaller than the fitting, so that it shall have a fair shoulder to clamp down. To better illustrate what I mean, Fig. 101 will show a section



Fig. 101.

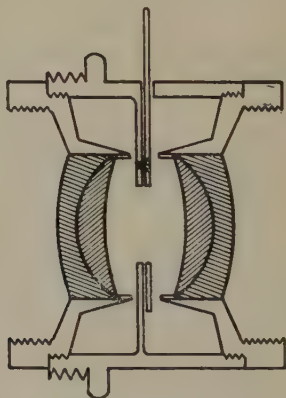


Fig. 102.

of the diaphragm and the screw. You must be careful to make the screw clamp on the mount so that the diaphragm can be turned round by the fingers. If you are not careful, you will get it so that it unscrews itself while you rotate it, or it will be too tight to move. You should screw it together once or twice to try it. If you were to slip the lenses in their cells

and screw all together, and cut in half, it would be as Fig. 102, or looking from the front, to show through as Fig. 103, which shows the lines cut in the face by the screw-tool.

The Iris Diaphragm. If you want an iris diaphragm, we shall have to proceed as follows. It can be made with as many leaves as you like; but eight, twelve, or sixteen are generally used. These we shall make



Fig. 103.

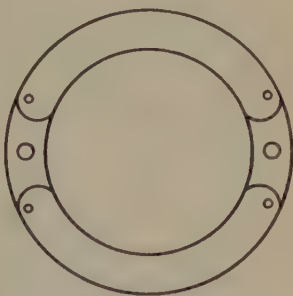


Fig. 104.

first. Get a piece of the thinnest hard-rolled brass, and if you determine on twelve leaves, cut roughly out seven or eight pieces to about 36 or 37 millimetres diameter. Now shellac on a chuck a piece of rather stout brass, and turn it to 32 millimetres outside and 27 millimetres inside; drill two holes for the clamp screws to go through to a face-plate, and mark the ring off like Fig. 104. Now drill all the pieces of thin metal so that the clamp screws go through; put them on the face-plate,

and clamp tight, having the stout piece of metal on top for a guide. Now turn them all to the guide inside and out, and drill a small hole that will just take a piece of brass wire 1.1 millimetre diameter through all at each of the places marked. If this is done properly, it should be as Fig. 105, which shows the circles finished on the face-plate. They can now be taken

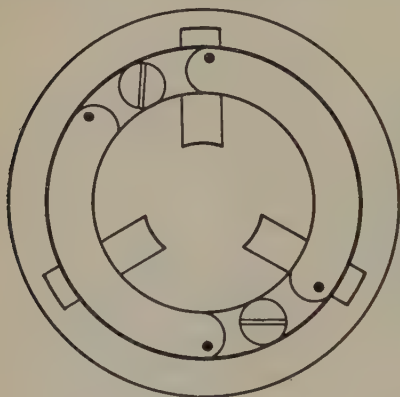


Fig. 105.

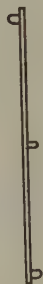


Fig. 106.

off, and cut round at the ends by a pair of scissors, so that every circle will make two leaves. Now get the piece of brass wire, and cut it into small pieces 2.5 millimetres long, and silver-solder one in each hole, one projecting one side and one the other, as in Fig. 106, and they can be put on one side till the box is made that holds them. To make this, get a casting or piece of thick metal; slide-rest the outside and one face,

so that it fits in the body of the mount. Now turn it out, so that it forms a shoulder rather wider than the leaves that are made. Divide the box round the shoulder into as many parts as the number of leaves, and drill a hole at each mark; that will allow the wire that you have formed the pins of to slip through easily, but not to let them shake. Get now a piece of metal and turn to fit in the box, and the same width as the

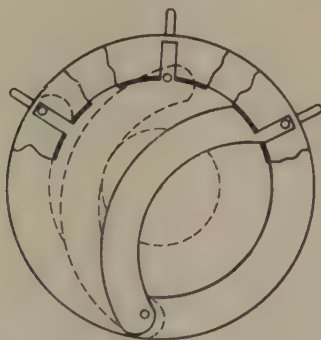


Fig. 107.

shoulder of it; then divide, and cut a slot instead of drilling a hole at each mark (see Fig. 94). Now, if we put one of the leaves in a hole in the box, lay it on the shoulder, putting the ring with the slots on to the top pin, and turn the ring round, we shall see the action of the diaphragm. As you turn the ring you will see the pin gradually run down the slot till it gets to the end of it, and if you look at its position you will find that the leaf is just half-way across the aper-

ture. Now keep on turning, and you will see that the pin now moves up the slot again; but the leaf continues to close till it reaches the centre, when the pin is at the top of the slot again. This is the whole

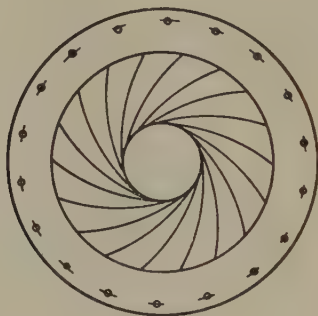


Fig. 108.

action of the diaphragm, and, of course, the more leaves you have the more circular the aperture will be. Fig. 107 will explain the action, and Fig. 108 will show an eighteen-leaf diaphragm put together.

CHAPTER X

THE APERTURE OF DIAPHRAGMS; A PHOTOGRAPHIC LENS AND ITS ACTION DESCRIBED

The Aperture of the Diaphragm. A keeper can now be made to lock the whole together, *i.e.* a ring of brass that will fit in the box of the diaphragm; this can be secured by two small brass screws. This ring

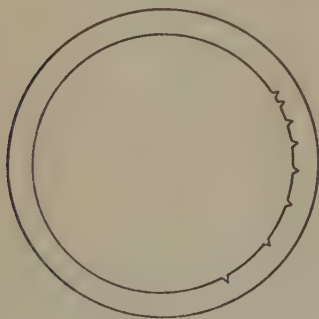


Fig. 109.

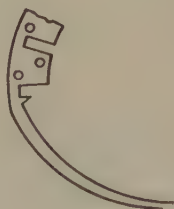


Fig. 110.

(Fig. 109) can be utilised for stopping the diaphragm to the different apertures. Make a spring of hard-rolled metal, like Fig. 110; put it on the driver by small screws; the ring will be rigid, and the spring will revolve on it. When the gauge for the apertures is

made, it can be put in the centre of the diaphragm, and that gradually shut till to the size required; the ring should then be marked where the catch of the spring comes, and when all the apertures are marked off it can be taken out, and the small **V**'s filed in, and the diaphragm is ready to be bronzed.

The Wheel Diaphragm. Fig. 111 will show the spring in position. Now, as regards the wheel dia-

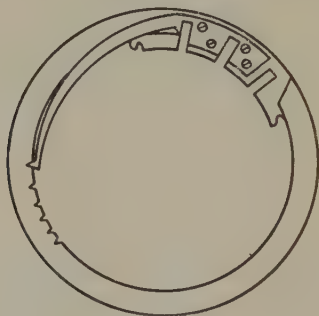


Fig. 111.

phragm, all that is required is to turn the apertures in it; this can be done on a small face-plate, or stuck on a boxwood chuck by shellac. The best way to get the centre is to put the diaphragm in the mount and screw home as if you were putting it together; then with a scribe or point draw a circle on the diaphragm, taking the central aperture of the body as a guide. Now get the centre with a pair of dividers, and drill a small hole through, as in Fig. 112. To make your

diaphragm accurate, turn a pin in the centre of your face-plate, or put one in your boxwood chuck that will just fit in the hole that has been drilled; clamp your diaphragm, and mark off the central hole of the diaphragm; drill and tap a hole, and put a screw through it to keep the diaphragm from moving. It is best to put the diaphragm in its place every time you want to turn an aperture out, just moving the disc sufficiently that the light is all stopped off, or you will not be able to get all the apertures in. Fig. 113



Fig. 112.

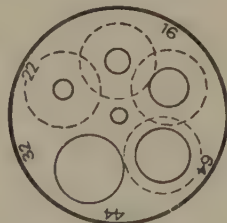


Fig. 113.

will show you a disc marked off properly, and the exact size of the apertures. This is now seldom used, for the degrees of rapidity are limited; but with an iris diaphragm you can get any you like. The lens and its setting is now practically complete, and all there is to do is to finish it. Before doing this, however, it would be as well to thoroughly understand what is meant by the terms "angle," "aperture," "focus," etc., and we will illustrate by showing the difference between a pinhole photograph and that taken by a lens.

Within the eye, a little behind the iris, is suspended a soft transparent body, called the *crystalline lens*, of the form of a double-convex lens, whose anterior surface is less curved than the posterior surface. The crystalline lens is contained in a thin transparent capsule, and is kept in its place by the ciliary processes. It is composed of successive layers, whose refractive indices increase towards the centre, its solid nucleus, which is of very small radius, refracting light most powerfully. This crystalline lens of the eye has the power of producing behind it a picture of the objects which are in front of it, which is formed upon a delicate nerve-tissue called the retina, and is effaced by every movement of the eye. In the case of a photographic lens, it is projected and permanently recorded on a film, on the surface of which is a chemical salt sensitive to light.

The Pinhole. To take the simplest form of an image-forming apparatus, we shall have to examine the eyes of some of the lower animals, which consist simply of a minute aperture. If we pierce a small hole in a card, and place it in the portion of the camera usually occupied by the lens, we shall find that a picture is formed upon the ground glass; and it will be noticed that wherever we place the focussing screen the picture will not be altered in sharpness. That is to say, when the focussing screen is 3ins. away, it will be as sharp as when it is 6ins. away. Therefore, unlike the photographic lens, a pinhole has no focus, so that all the objects in the picture,

whether they be close to the camera or on the horizon, are equally sharp, so that a pinhole has great depth of definition, and as long as the plane of our ground glass is vertical the straight, horizontal, and vertical lines in nature are straight, horizontal, and vertical in the picture; therefore our pinhole does not in any way distort the picture.

On the length of focus depends the size of the picture. Upon the distance of the ground glass from the pinhole depends the size of the various objects in the picture. If the ground glass be close to the pinhole, the whole of the view will be crowded in, the scale being much reduced in size to enable the picture to include the larger angle of view, and if the ground glass be some distance away from our pinhole, a small portion of the view will be in the picture; but the scale will be much larger, each subject in the view being enlarged to cover the plate, so that the angle of a pinhole and the size of the objects will only depend on the distance of the ground glass from the pinhole.

Exposure of a Pinhole. When taking a photograph by a pinhole, the photographic plate must be exposed for a very long period, in order that the small amount of light which is admitted may have time to affect the salts, so that for practical purposes it is of little use as a picture-forming apparatus. Fig. 114 will at once explain these facts. Let AB represent a card with a pinhole, K , and CD an illuminated object. CD is giving off rays in every direction from every point, as at CE and D ; and, as the light travels in straight

lines, it is evident that but one ray or a very small cone of rays from each point in the object will travel in the direction of the pinhole K ; consequently no confusion of rays can take place either at FG or HJ , and a correct image will be formed in either plane. If instead of a pinhole, however, a large aperture ad-

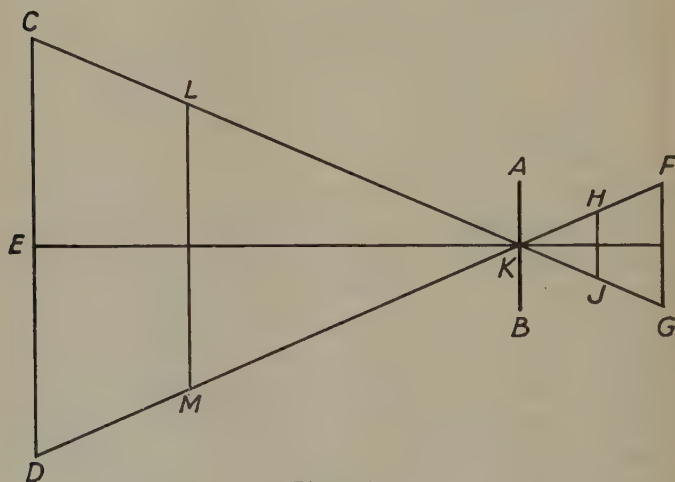


Fig. 114.

mitting more light were at K , the rays would become at once confused, and no picture, or but an indistinct image, would be formed. It is evident that whether the ground glass be placed at HJ or FG the image will still be formed, and will be as sharp in one position as in the other. This explains why a pinhole has no focus. Again, if the object CD were placed at

LM , the image formed would be equally sharp. In fact, the image is a true single-ray projection, and

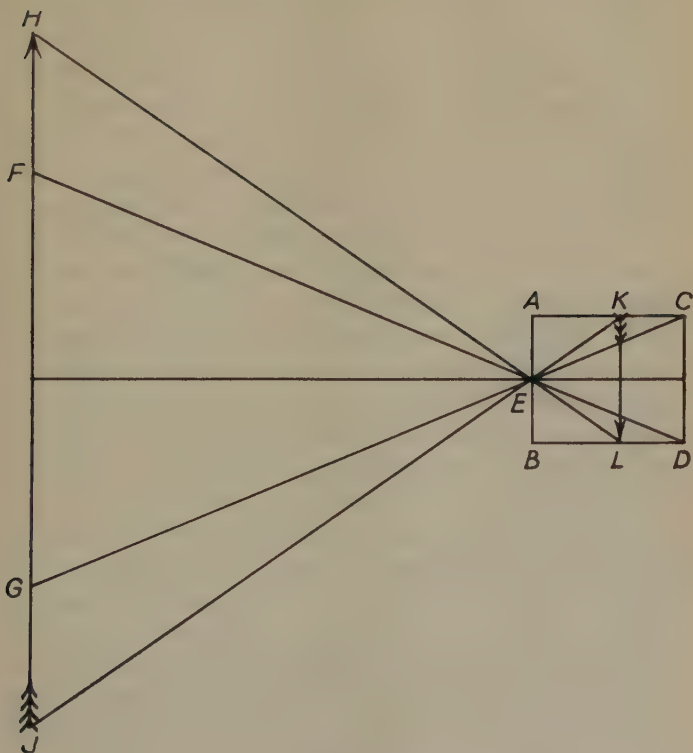


Fig. 115.

therefore a pinhole has unlimited depth of definition, and from the fact that it is a true projection there is no distortion. The size of the image and the amount

included in a given size picture are entirely dependent upon the distance from the pinhole. Fig. 115 will explain this. Let $ABCD$ represent a light-tight box or camera. AB is the front, having a small aperture or pinhole; at CD is a sheet of ground glass, which can at will be moved towards AB . If the ground glass be placed at CD , an inverted picture of any illuminated object or view at FG will be projected. Upon the ground glass being brought forward to KL a more extended view, HJ , will be projected, and consequently the proportionate size of objects in the picture will be smaller, though perfectly sharp. If, however, the ground glass be exchanged for a sensitive plate, we shall find that, as one ray of light only from each point in the object is received upon the plate, the effect produced upon the sensitised surface is so slight that for ordinary photographic purposes it is useless.

A Lens to form an Image. Having thus observed the effects of a pinhole when used as an image-forming apparatus, we are in a position to consider the points in which a lens differs from a pinhole. The five points described are the fundamental properties of a lens which influence the question as to what form of lens should be used for any particular purpose, and these points may be generally defined as follows:—

Focus.—The distance from the lens of the plane in which the image is formed.

Depth of Definition.—The power of a lens to give a sharp definition in one picture of objects at different distances.

Angle of View.—The amount of field covered by the lens.

Rapidity.—The amount of light or number of rays allowed to pass through the lens to the sensitised plate.

Distortion.—The conversion of right or straight lines at the edges of the plate into curved lines, or the convergence or leaning together of lines which should be parallel.

A lens differs essentially from a pinhole in the fact that, instead of forming an image of the object by allowing only one ray of light from each point to pass through it, it collects as many rays of light as possible from each point in the object, and bends them so that they meet again at a point on the other side of the lens to form an image. A good lens should produce a picture practically in one plane, giving a sharp definition of each object. It is owing to glass having the property of bending light that we are enabled by various shapes and arrangements to produce this result. The ability to so construct photographic lenses that the image is as perfect a reproduction as possible of the object constitutes our skill.

It will be observed from examination of Fig. 116 that, as the lens collects a large number of rays from each point in the object and bends them to another point, one particular lens can only form its picture in one plane, and the distance of this plane from the lens is called its focal length. In Fig. 116 *AB* represents a lens, *CD* the object, and *EF* the inverted image

formed. The pinhole in Fig. 114 would have allowed practically but one direct ray of light from each point of the object to pass through to form the image at EF ; but the lens not only allows one direct ray of light through, but the whole cones of rays ABD , AGB , ACB , and collects them again at the points

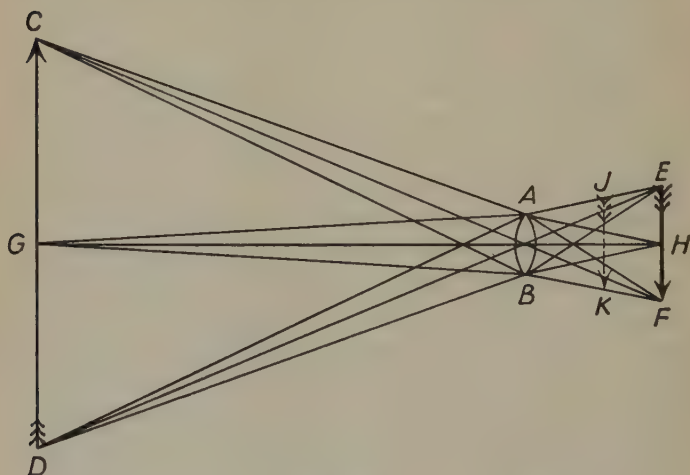


Fig. 116.

F , H , E , which will all be found to lie practically in one plane at right angles to the axis of the lens.

The larger the lens, the more light it admits. It may be noted here for future reference that the greater the diameter of the lens AB , the larger the number of rays it must collect from each point in the object, provided the distance of the image EF remains

fixed. It will be seen, too, that the plane EF occupies the only position the image can assume, since, if it were either further from or nearer to the lens at JK , a confused mass of rays would result at each point. Therefore, whereas a pinhole has no focus, every lens has a focus, and this forms the first important point in the selection of a lens, as upon the focus of a lens depend, first, the size of the picture; secondly, the angle of view included; thirdly, the depth of definition; fourthly, the covering power of a lens, or the size plate on which it will give a sharp picture in relation to its rapidity. As to the size of the picture, on referring to Fig. 114, it is clear that, if a lens were of such focus that the image of CD were formed at JH , the picture would be smaller than if formed on FG . The other points referred to will be treated of under their respective heads.

Depth of Focus with a Lens. We have seen that a pinhole has an unlimited depth of definition—that is, that objects at all distances from the camera will be sharp in the picture. In a lens, however, this is quite different. If a photographic lens be placed on a camera, and the ground-glass focussing screen be moved backwards and forwards, it will be found that where the image of an object at 10ft. distance is sharp on the ground glass that of an object at 100ft. is indistinct. By moving the ground glass, however, rather nearer to the lens, a position will be found where the image of the object at 100ft. is sharp; but at this position the image of the object at 10ft. is

indistinct This is the reason for the focussing adjustment in all cameras. Although a lens theoretically has no depth of definition, for practical purposes it has a considerable amount. In Fig. 116, although theoretically CD is the only object that is absolutely sharp at the position EF' , objects which are situated very close to CD have their pictures formed so close to EF that they are for all practical purposes quite sharp. That is to say, every lens has a certain amount of depth, and it is important to see upon what this depth depends. It will be found to be influenced in a perfectly corrected lens in two points only. First, the length of the focus of the lens, for the shorter the focus of a lens the greater the depth. This depth varies inversely as the square of the focus. Thus a lens the focal length of which is half that of another will give four times the depth; or, in other words, a lens having a focal length of 3ins. will give four times the depth of one having a focal length of 6ins. Secondly, the aperture of a lens: the more nearly the lens approaches to a pinhole, the greater the depth becomes. A lens is therefore provided with an adjustable apparatus called a diaphragm, one of the chief uses of which is to produce this quality where it is required.

Light Modified by Diaphragms. There are several forms of diaphragms, but they all regulate the amount of rays allowed to pass through the lens by reducing the aperture. By stopping down the lens, however—*i.e.*, reducing the aperture—the rapidity of the lens is reduced, and a longer exposure is necessary. Distor-

tion is produced by two distinct causes. In the first place, both in the case of a pinhole and a lens, the photographic plate must be vertical, or the lines will converge or diverge. For instance, if the whole camera be tilted up to photograph a building, the lines which should be parallel will lean together unless the swing-back, which is provided in most cameras, be used so that the plate is vertical, although the camera is tilted. The other cause of distortion is the fault of the lens. It can readily be understood that, inasmuch as the lens is used to bend the rays of light which enter it, it must do so symmetrically in every direction, or distortion will be caused. This distortion is always distinguished from the form caused by the position of the camera by the fact that the lines of the picture, which should be straight, are curved. It should never be present in any good lenses.

There is much misapprehension on the point of angle of view, and in order to explain the factors influencing the angle of view, the pinhole analogy will be most useful. If we consider the case of the camera being pointed at an open landscape where the horizon can be seen all round, it will be obvious that, with a pinhole and a large photographic plate behind it, almost the whole of the panorama might be included in the picture—that is to say, we might be able to include some 130° or more. In this case the angle of view would be very large, and we should be using our pinhole as a wide-angle lens. If we were to take our photographic plate a great distance away from our pinhole, the cen-

tre of our panorama only would be in the picture, and the pinhole would be acting like a narrow-angle lens. The question of the angle of view included is dependent only upon the size of our photographic plates and the distance of the plate from the lens or pinhole.

A pinhole can be used at any angle. In the use of a pinhole, the photographic plate may be varied in position, and therefore different angles of view may be included in the same picture with the same pinhole. In the use of a given lens, however, the plate, in order to give a sharp picture, must be in a particular place—namely, the focus of the lens—and therefore the angle of view cannot be altered with a given lens and a given-sized picture—that is to say, the angle of view included in a picture only depends on the size of the plate as compared with the focus of the lens, whatever may be the optical construction of the lens. Because a lens is called a wide-angle lens, it does not mean that it will include a larger angle of view than a narrow-angle lens of the same focus if used on the same size plate. What it does mean is that the wide-angle lens is optically constructed so that it will make a picture, if desired, on a larger plate than a narrow-angle lens would, thus including on this large plate a wider angle of view, whereas the narrow-angle lens is only constructed to form the picture on a small plate. Thus a 7in focus wide-angle lens used on a 5 by 4 plate would give exactly the same picture as a 7in. narrow-angle lens used on the same plate. But supposing we are using a 12 by 10 plate, we shall find

that our 7in. wide-angle lens will give us a picture on the whole surface, thus including a very wide angle of view; whereas we should find that the narrow-angle lens, not being constructed to cover a large plate, would send no light at all to the margin, but would only form a small picture in the middle. In order to make a wide-angle picture on the 5in. by 4in. plate, a lens of a focus of 3ins. would be required. Therefore the term "wide-angle," as applied to a lens, means that such a lens is optically constructed to make a picture, if required, on a much larger plate, and including a much larger field, than the lens of the same focus of another type.

Rapidity of a Lens. We saw that in the use of a pinhole, the action of which depended on the fact that only one or a very small number of rays of light from each point entered the camera, the rapidity was very small; that, in fact, a very long exposure would be necessary to take a photograph. We further saw that the action of a lens was not to select one ray from each point of the object, but to collect a large number of rays of light from every point in the object, and bring them to a point in the picture. It is therefore evident that the lens, admitting so much more light into the camera, requires a shorter exposure to take a photograph.

We will now see on what the rapidity of a photographic lens depends. It is mainly dependent on three elements. First, the aperture of a lens—that is to say, the size of the diaphragm in relation to the focus.

If a small diaphragm be used in a lens, it is evident that a smaller amount of light enters the camera, and the photograph will need longer exposure. Secondly, the shape and number of glass surfaces which reflect light away. Light, when it passes through glass, is always somewhat weakened by the fact that a certain portion is reflected back. Other things being equal, therefore, the fewer the number of reflecting surfaces the better. Thirdly, the colour and transparency of the glass used. The two latter elements are so unimportant in relation to the first that they can be discarded.

The rapidity of a lens depends on the aperture or size of the diaphragm. This is now almost always measured on a system which makes it possible to compare the relative rapidities, whatever their focus. *The size of the diaphragm is calculated as a fraction of the focal length—i.e., the stop $f/4$ admits a beam whose diameter is one-fourth of the focal length of the lens*, and all lenses having an aperture one-fourth of their focus are equal in rapidity, on the supposition that the other two causes of rapidity are neglected. On this system all lenses are supplied with stops or graduations to their diaphragms, each of which requires double the exposure of the last to produce the same effect on the sensitised plate, and this makes it simple to calculate the difference in exposure which is required when a change in the stop is made. The series of apertures which have been selected as most generally useful, and which have been introduced as

a standard by the Royal Photographic Society of Great Britain, are as follows—

Aperture—

<i>f</i>	<i>f</i>	<i>f</i>	<i>f</i>	<i>f</i>	<i>f</i>	<i>f</i>	<i>f</i>	<i>f</i>
4	5·6	8	11·3	16	22·6	32	45·2	64

Relative exposure ratio—

1	2	4	8	16	32	64	128	256
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For example, one lens has a maximum aperture of *f*8, and another of *f*11·3. The former, when used at its greatest rapidity, will be twice as rapid as the latter, whereas, if the *f*8 lens were stopped down to the first stop (*f*11·3), it would then be the same rapidity as the *f*11·3 lens with full aperture.

Finishing the Setting. To finish the lens we shall require some lacquer, vegetable black, nitric acid, methylated spirit, a small piece of copper, lacquer brush, and a small pencil brush. To make the bronze, or more properly the black—as it is dead black when done—get $\frac{1}{4}$ lb. of nitric acid; pour it in an earthenware pot; stand it in an open space that the fumes can easily get away. Now put in $\frac{1}{4}$ oz. of copper wire, and let it eat it all away; be careful not to breathe any of the fumes. When it has stopped boiling, add $1\frac{1}{4}$ oz. of water. This is now ready for use, and you can proceed to bronze all the parts requiring it. To do them you must heat the pieces in a spirit-lamp or gas-jet—a Bunsen for preference—taking care not to smoke them, and when you immerse them in the nitric bath, they should just hiss. Take out, draining as much as you can back, and burn all the green off till all goes black.

When cold, get a brush and a little powdered black-lead, and brush all the corrosive off, and you will find that your piece of metal has turned to a beautiful black with a fine granulated surface. You must do the iris diaphragm, each part and leaf separate, the cells and the wheel diaphragm. To black the inside, get a little vegetable black and put it in a cup or pot; make it into a stiff paste with the lacquer you are going to finish the jacket with. Now, if you thin it down with methylated spirit so that it will run through

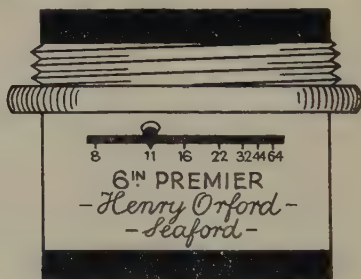


Fig. 117.

fine muslin, you will have a good dull black that requires little heat to put on, and will not rub off. The cold lacquers obtainable from the Frederic Crane Chemical Co., Ltd., Birmingham, also give good results. The heat required to put a good coat on will soon be found with a little practice. Last of all, the two combinations can be bevelled true in their cells, and all put together. The wheel diaphragm can be stamped, and the numbers filled in with a little Chinese white; or if the iris be used, the different stops can be engraved on the jacket, as in Fig. 117.

CHAPTER XI

EYEPieces AND THEIR SETTINGS

EYEPieces and condensers are among the most simple jobs to do, and many, no doubt, would like to have a try at them; so I shall describe the different styles of eyepieces and condensers, with working drawings and the glass used, beginning with the Huygenian eyepiece and following with the Ramsden, the Kellner, aplanatic and orthoscopic compensating eyepiece, erecting eyepiece, spectral eyepiece, the Abbe condensers, achromatic condensers, Webster's condensers, etc.

Glass for Eyepieces. The glass used for ordinary eyepieces can be either French plate or British; but the eye and field should always be the same stuff, and if it be very clean and flat, you can dispense with working the plano; but if the best results are required, it is always best to have them worked. When working the lenses it must be borne in mind that the surfaces must be absolutely clean. No scratches, or marks, or air-bubbles, however small, can be tolerated. Get two pieces of French plate; shank them round to about 1.25 and .8; grind up to the curves; emery and polish, getting as brilliant a surface as possible. Then edge to the following diameters: the field-lens to 1.2, and the

eye-lens to 7. Fig. 118 will give the size of the gauges and the edging diameters. This is the ordinary A eyepiece used in large stands. The working of the lens does not differ at all from that described in making a camera lens. The figure is not so particular as in an object-glass; but the better it is the more perfect

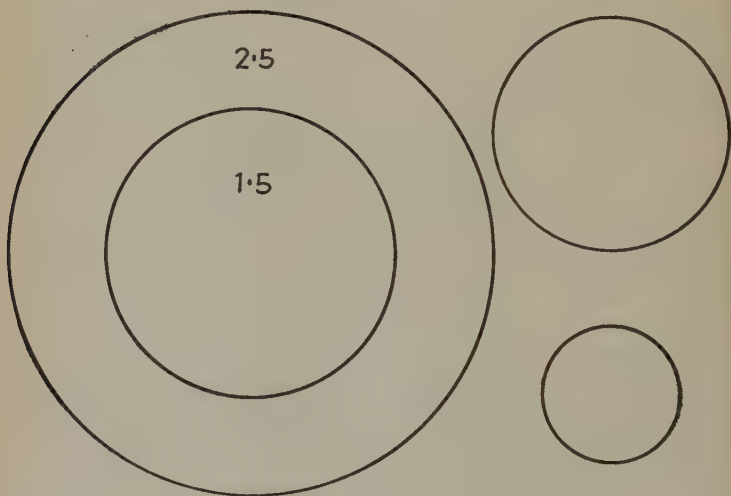


Fig. 118.

results your microscope will give. The eyepiece is intended to refract the diverging pencils of rays which form the real objective image that they may all arrive at the pupil of the eye. It has also to form the virtual image as perfect as possible of the real image, which is presented to it as the object. If a single lens were used, it would only show the object distinctly in the

centre of the field of view, and on account of the chromatic aberration would produce a confusion at the peripheral points, since the pencils of rays emerging from the points pass through the margin of the lens. The introduction of a third lens between the eye-glass and the objective will considerably increase the field of view of the instrument, hence the term for the larger lens of the eyepiece, the "field-lens."

Mounting Eyepiece Lenses. If the lenses are worked properly and edged, we must proceed to make a suitable mount for them. The first thing to be done is to get the distance the lenses are to be apart, and then design your eyepiece to it. A very good rule is to make your eyepiece the distance of the diameter of the curve the field-lens is worked to; in this case, as the curve is 2.5, 2½ins. will be the distance from the plano of the eye-lens to the curve of the field. Fig. 119 will show the position of the lenses and the stop. If you use this rule for all Huygenian eyepieces, you will not be very far wrong. Now to get the size of the stop. If you make it slightly smaller than the diameter your eye-lens is worked to, and push it down the body till it is quite sharp, you will have little fear of the edge of the field-lens coming into view. To make a best eyepiece cut off 2ins. of tube that will fit into the draw-tube, and screw each end inside with a thread of about fifty-six to the inch. Now get two more pieces of tube, one fitting over the other, for the cap and neck. The neck or inner tube should be about eight-tenths inside; cut them both off ¾in. in length. We shall

want five discs of metal for the flange, eye-cell, eye-cap, flange-stop, and field-cell. The disc for the flange should be rather stout, as it will require a thread cut on it, and enough left to make a rather stout shoulder with a milling. Put this disc in a wood chuck, and slide-rest it down till the main tube will

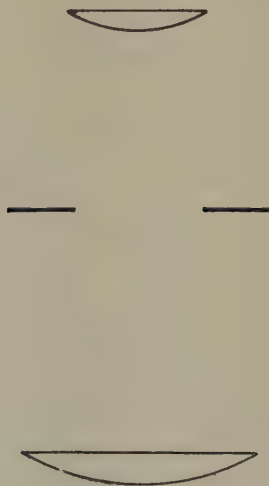


Fig. 119.

screw on—half a dozen threads will be enough; then slide-rest the inside level with the shoulder. The back cell should be chucked and screwed to the tube also, and the lens fitted in its shoulder at the same time. A chuck to run on the lathe, with a screw to take the tube, will enable you to finish the field-cell on it by

turning it down just under the diameter of the tube, turning the back and inside true, and putting a milling on. The flange is next slide-rested over, and a milling put on the edge, and the face papered with rather fine emery paper. Next put the neck tube on a chuck, and turn it down $\frac{1}{10}$ in. from the end. Then fit the flange on to it, making the fitting in the flange taper from the front. When the neck is fitted it can be turned

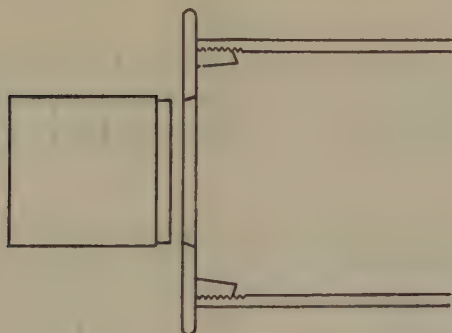


Fig. 120.

and polished, and that and the flange can be put together, and the fitting of the neck run out by means of a burnisher or the arm-rest. Fig. 120 will show the two ready to be run together. By this means you avoid using solder, and if you lacquer the flange first you make a much neater job of it. Now get the disc for the eye-cap; slide-rest it out, and screw it to the fitting tube; then put it on a chuck and hollow it out,

putting a milling on the edge. Fig. 121 will show the tube and cap finished. Make the eye-cell as in Fig. 122. bronze and bevel. The fitting of the field-cell

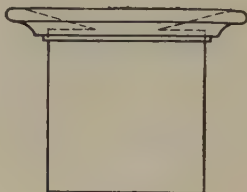


Fig. 121.

is different from the eye, as will be seen from Fig. 123. When the stop is turned and fitted, all the parts will be done, and the eyepiece can be lacquered and blacked inside.



Fig. 122

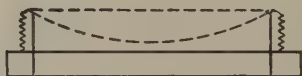


Fig. 123.

CHAPTER XII

CURVES OF HUYGENIAN EYEPIECES; THE RAMSDEN EYEPIECE
THE KELLNER EYEPIECE

Huygenian Eyepiece. The different curves for the Huygens eyepiece are as follows. The A has already been described :—

		B.				Diameter of Curves.	
Diameter of Lenses.							
Field-lens	1·2	.	.	.	.	1·76	+
	Plano						
Eye-lens	·6	.	.	.	.	1·1	+
	Plano						
C.							
Field-lens	·9	.	.	.	.	1·36	+
	Plano						
Eye-lens	·45	.	.	.	.	·66	+
	Plano						
D.							
Field-lens	·8	.	.	.	.	1·06	+
	Plano						
Eye-lens	·35	.	.	.	.	·53	+
	Plano						
E.							
Field-lens	·42	.	.	.	.	·75	+
	Plano						
Eye-lens	·21	.	.	.	.	·8	+
	Plano						

		F.					Diameter of Curves.	
Diameter of Lenses.								
Field-lens	·32	.	.	.	.	.	·5	+
Plano								
Eye-lens	·12	.	.	.	.	.	·2	+
Plano								

CONTINENTAL EYEPieces.

No. 1.

Field-lens	·9	.	.	.	.	.	1·8	+
							24·	—
Eye-lens	·45	.	.	.	.	.	·9	+
							24·	—

No. 2.

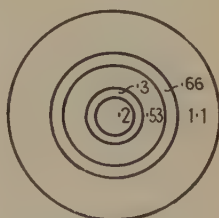
Field-lens	·9	.	.	.	.	.	1·36	+
							21·	—
Eye-lens	·35	.	.	.	.	.	·66	+
							24·	—

Fig. 124 will give the curves of the fields and eyes of the English eyepieces, also the edging diameters of same; Fig. 125 those of two of the Continental eyepieces for use with the short body. The Huygenian eyepiece is most generally used in microscopes, and Fig. 126 will more clearly explain its action on the image formed by the objective. Rays proceeding from the object-glass would meet in *A*, *AB* being the principal focal plane of the object-glass; the rays are caught by the field-glass before reaching *A*, and are brought to a focus at *A'*, which is in the focus of the eye-glass, so that the rays will emerge parallel to each other, the image being formed exactly where the stop is bounded, as it were, in a frame.

Ramsden Eyepiece. On special occasions other forms may be applied with advantage, and among the best known is the Ramsden, though it is commonly used as an astronomical eyepiece. Here, however, the two



Curves of English Fields.



Curves of English Eyes.



Dia. of Fields.

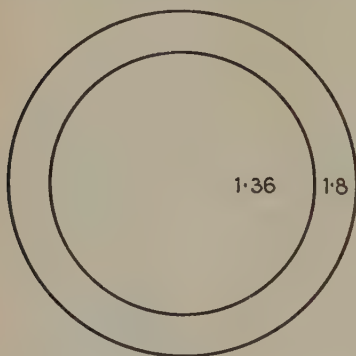


Dia. of Eyes.

Fig. 124.

lenses are of equal focus, and, therefore, to be perfect, they should be at a distance of their focal length from each other; but if this were to be done, the field-glass

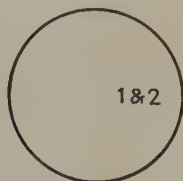
being in the focus of the eye-glass, any marks, dust, or splinters would be magnified by the eye-glass, and would spoil the image, so that it is usual to have the distance a little less than the focal length, though not



Continental Fields Gauges.



Continental Eye Gauges.



Size of Fields.



Size of Eyes.

Fig. 125.

being perfectly right, it is hardly noticeable. The combination thus forms a magnifying-glass, and it is to the advantage of the final image, because it is not first diminished and then magnified, as is the case with

a Huygenian eyepiece, but is magnified by each lens. The final image formed just in front of the second lens, sharpened by the diaphragm, appears (if the lenses are of equal curvature to the Huygenian eye-

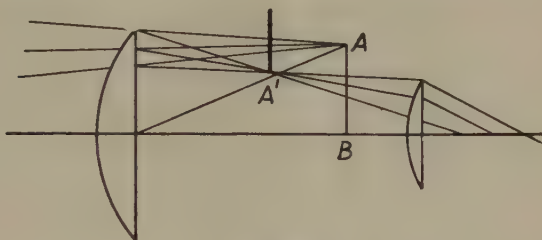


Fig. 126.

piece) considerably larger than the image formed by the Huygenian, and has a much larger field. It is especially serviceable for measurements by the eyepiece micrometer. Fig. 127 will show the system, and where the image is formed.

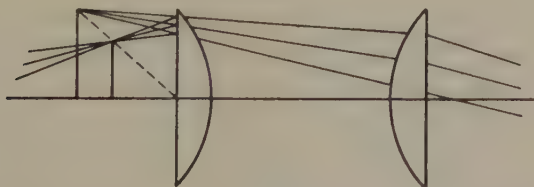


Fig. 127.

Kellner Eyepiece. Next we come to the Kellner or orthoscopic eyepiece. This is composed of an achromatic pair of lenses in the place of the ordinary eye-

lens; and the field-lens, in order to still more flatten the image, is an equi-convex. The eyepiece gives a large field, though there is little improvement in other directions; in fact, it is rather a nuisance, as it wants continual wiping, for the field combination is, or should be, exactly in focus of the eye, and, like the Ramsden, magnifies the least speck of dust into an eyesore. The field is often put just out of focus for this reason. A stop must be placed just above the field-lens; for however careful you may be in edging and chamfering, the edge of the field will not be so sharp as a turned stop. Many makers overdo it for the size of the field, and the result is an indistinct ring, or you have to put your eye so close to the eyeglass that there is some danger of poking it out before you catch sight of the edge of the field. To make a Kellner we shall want three pieces of glass: a piece each of Chance's heavy flint and soft crown and a piece of French plate. Make a small pair of tools for the shallow curve of two discs of metal to the size of 2·27, and work carefully the shallow sides of the eye system. You can grind out the curve, as it is very shallow, and to more easily hold it you can put a small pitch-mallet on to it; but you must bear in mind that if it is too long it is very liable to jump off the tool and splinter. To emery it you will require the slowest speed, and be careful to emery it very fine. You can put a polisher on to the tool with pitch, and polish it as level as possible, taking care that it is very bright and free from streaks. Next make a pair of tools to ·5,

and turn the other side of the flint out, leaving a substance in the centre of $\cdot 03$; turn the crown to the curve, and work the pair, rubbing the tools together with a little emery before using the finest, and then polish them. Next turn a small runner of $\cdot 3$ diameter and hollow it out to slightly deeper than the $\cdot 5$ curve, stick the worked side of your crown on, and work to a curve of $\cdot 33$; get it to a very sharp edge at $\cdot 3$, and polish. If you stick the flint on to an edging chuck, and edge same size as crown, you can put a clean chamfer on the shallow side of the flint, and balsam

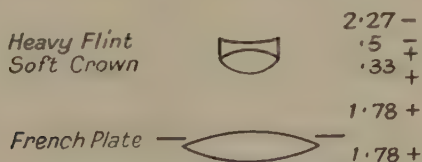


Fig. 128.

together, setting the pair true on a ring-chuck, as before described. You can either turn or grind up the field-lens to an equi-convex of 1.78 diameter each side. You can get the exact distance the field-glass should be from the eye by measuring with a rule. Pin a piece of white paper on a wall, and have a small light burning at a distance of 12ft. away from it; put the rule at right angles from the wall, and focus the light through the eye combination to a sharp image. You can then see which division the chamfer of the shallow surface is nearest to; so if you mount your eye-lens in

a cell, you must put your field-lens at the distance measured from the paper, or slightly increase it for the reasons stated. When you have put your eyepiece together, get a stop, and keep on turning it out as long as you conveniently see the edge of the field sharply defined; it is of little use having the field larger. Fig. 128 is a working drawing of a Kellner eyepiece, as deep as it is convenient to go; but eyepieces of less magnifying power can be ratioed from it.

CHAPTER XIII

COMPENSATING EYEPIECES ; PROJECTION EYEPIECES ; ERECTING
IMAGE IN EYEPIECE BY PRISM ; ERECTING IMAGE BY EXTRA
LENSES IN EYEPIECE

THE compensating eyepiece is made similar to the ordinary Huygenian, with the exception that the eye combination consists of an overcorrected triple lens in place of the single eye-lens. The field may be either equi-convex or plano-convex. The chief use of these eyepieces is to correct the outstanding aberrations of objectives.

Relation of Compensating Eyepiece to Objective. All objectives of considerable aperture, from their having hemispherical fronts, exhibit certain colour defects in the extra-axial portion of the visual field, even if perfectly corrected in the centres. The different coloured images which combine to form the final images are of different dimensions, the blue image being greater than the red one. Whether an image be directly projected by such an objective, or whether it be examined by an eyepiece (even of the Kellner or aplanatic type), colour fringes will be observed increasing towards the edge of the field. To compensate this, these eyepieces are employed. They are made to possess an equivalent error of opposite sign—that is,

the image formed by the red rays is greater than that formed by the blue. Such eyepieces serve to compensate the unequal magnification of different colours, and the image appears free from colour up to the margin of the field. These eyepieces are mostly used with apochromatic objectives, and it is useless to use a com-

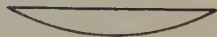


Fig. 129.

Fig. 130.

pensating eyepiece unless the objective is by the same maker, and I have frequently seen an objective condemned by the use of another maker's eyepiece. Fig. 129 will show the construction of the system, but the deeper eyepieces can be made of a pair and a field-lens, the latter placed very close to the eye, and the stop

between the field-lens and the objective; but this need not be illustrated, as an amateur will not be very likely to construct one.

Projection Eyepieces. Projection eyepieces are used for projecting the image formed by the objective on a screen for demonstrating purposes, or on a photographic plate. They consist of a convex field and a compound eye-lens system, which is most carefully corrected, both spherically and chromatically, after the principle of apochromatic lenses, and they are entirely free from secondary chromatic aberration and from difference of focus between the visual and chemical rays. A diaphragm is placed between the lenses limiting the field, and the compound lens can be made to approach to or recede from this diaphragm. The cap of the projection eyepiece forms a diaphragm by which internal reflection in the body-tube is entirely obviated. Fig. 130 shows the system. These projection eyepieces work either with the apochromatic lenses or ordinary achromatic systems.

Erecting Eyepiece. An erecting eyepiece can be made as follows:—To the ordinary eyepiece two other lenses are added, which are inserted in the body of the microscope, convex sides towards the eyepiece end. The eyepiece thus made is identical in arrangement with that of the terrestrial telescope, and therefore causes a reinversion of the objective image (Fig. 131). The reinversion of the image may also be produced by use of a prism, either above the eyepiece or in the body of the microscope. The action of a right-angled prism

employed for this purpose is shown in Fig. 132. It produces a lateral inversion, but none in a direction at right angles to the plane of the paper. To complete the inversion a second prism at right angles to the first must be added. It is evident that such a combination can be replaced by a single prism, so constructed that two equivalent total reflections take place within it.

The most practical contrivance is an erecting prism enclosed in a box, which may be attached or removed at will (Fig. 133). Its underface is at right angles to



Fig. 131.

the axis of the microscope, and forms an angle of 58° with the upper face. The inclination of these faces is calculated to bend the optic axis to an angle of 30° from the horizon, which is convenient for working. The faces *a, b, c, d* and *b, c, e, f*, which meet in the edge *CB*, are the reflecting ones. They form an angle of $81\frac{1}{2}^\circ$, so that the planes of reflection of rays incident from beneath cut one another at right angles. The other faces have no optical action. The underface may be made convex to take the place of the eye-lens, thus doing away with two flat surfaces, and thereby

gaining more light. The working of the prisms both for this and the following spectral eyepiece will be

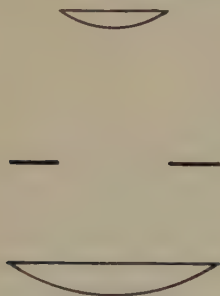


Fig. 132.

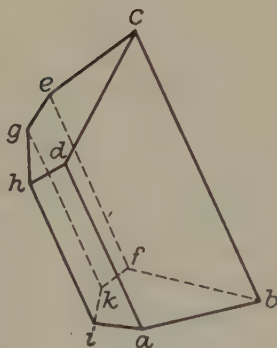


Fig. 133.

treated in a special chapter on prism work; but these being drawn the proper sizes, they can be worked from.

CHAPTER XIV

SPECTRAL EYEPieces; BINOCULAR EYEPieces; MICROMETER
EYEPieces; BEALE'S CAMERA LUCIDA

Spectral Eyepiece. The best description of the spectral eyepiece is given in that excellent work by Nageli and Schwendener in the *Microscope*, and is as follows:—"Microspectral apparatuses have been recently made which not only serve for the investigation of microscopic objects, but have also proved useful for other spectro-analytical researches. They consist of arrangements to be applied to the eyepiece of the microscope, and may, therefore, be termed spectral eyepieces." The best apparatus of this kind is that constructed by John Browning, of London, after his own design and that of Mr. Sorby. It consists of an ordinary eyepiece, of which the tube *a* (Fig. 134) fits into the body-tube. Between the field-lens *n* and the eye-lens *m* is a prism, *p*, which lies in contact with the diaphragm, *s*. The diaphragm is in the form of a slit, which may be diminished in length or breadth by a special contrivance. At the side is an opening, *o'*, through which the light from the objects serving for comparison spectra falls upon the prism, and is totally reflected through the series of prisms above to the eye

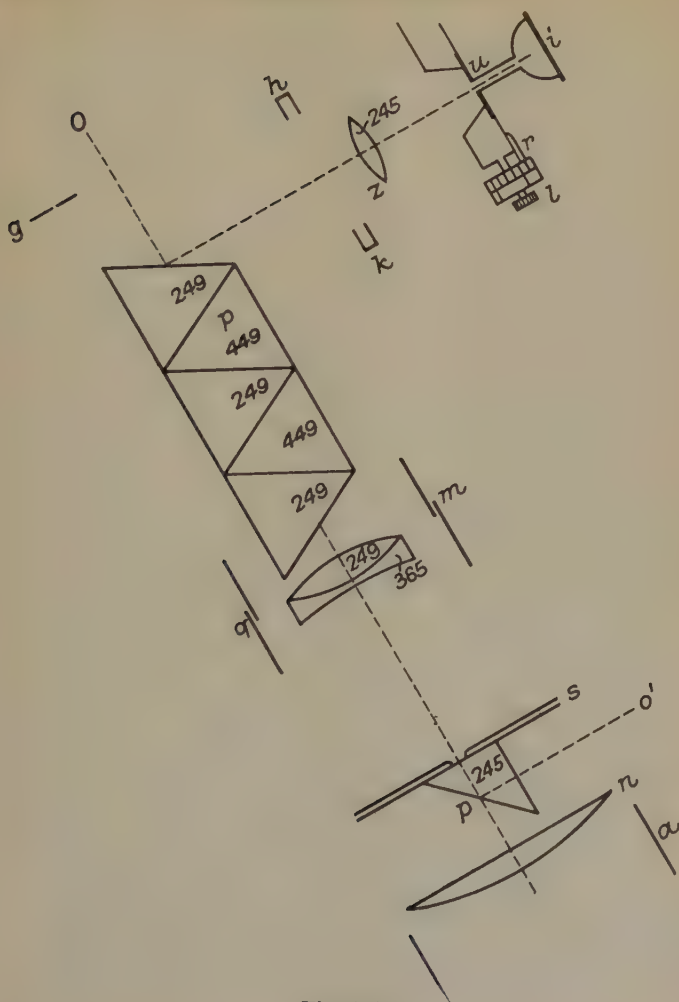


Fig. 134.

of the observer at *O*. This apparatus may be used for observing the spectrum of the Olga chlorophyll-green placed on the microscopic stage, and simultaneously the comparison spectrum of a solution of chlorophyll in alcohol in a small test-tube placed in front of the aperture at *o'* on a specially devised stage. The analysing prism is applied above the eye-lens *m*, and is removable. It is composed of two flint and three crown-glass prisms, and acts in such a manner that the light reaches the eye in a direction parallel to the axis. If we look through this prism down the microscope in ordinary daylight, and adjust the opening of the diaphragm properly, a spectrum of unusual clearness and brilliancy is seen, in which the lines from *B* to *G* appear with extraordinary sharpness. With sunlight the spectrum extends from *a* to the two lines *H*, and appears as though covered with innumerable fine lines. The best part of the spectral eyepiece is the ingenious apparatus for measurement contrived by Browning, which is applied to the side tube at *h*. It consists of a mirror, *i*, which throws a light into the tube, and a blackened plate, *u*, on which is drawn a bright cross formed of two lines at right angles; a lens, *z*, which may be so adjusted that the image which it forms of the cross is reflected by the upper surface of the analysing prism to the eye of the observer; a screw, *l*, by means of which the blackened plate *u* can be so moved that the image of the cross traverses the whole spectrum, which can then be adjusted to any particular point of it. As this screw is

connected with a micrometer milled head, it is possible to determine what adjustment, for instance, corresponds to the Fraunhofer line *B* or *C*, etc. In order to determine conversely the position of a given line in the spectrum (*e.g.*, of an absorption line of a solution of chlorophyll), it is only necessary to set the cross to it to read off the position on the milled head.

A binocular eyepiece can be made of prisms and a pair of eyepieces that can be used on an ordinary short-body monocular microscope. This binocular will give fair results with the higher powers. The division of the pencil of rays emerging from the objective to produce two separate images is effected at the upper end of the tube by partial reflection at a thin stratum of air between the two glass prisms *A* and *B*. The direct rays proceed to an eyepiece, *B*, arranged in the axis of the tube. The reflected rays undergo another reflection through a prism, *C*, in a second eyepiece, *C*, placed excentrically, so as to make its axis and that of the tube include an angle of 14° . Both eyepieces must give equal magnification. The excentric eyepiece may be adjusted by screws to suit the width of eyes of the observer. Bisection of the pencil for producing stereoscopic effects can be made by putting adjustable diaphragms above the eye-lens, and a careful adjustment of these, combined with a good objective, will give very good stereoscopic effect.

Binocular Eyepiece for Monocular Microscope. When the stops are opened too large, an ordinary binocular effect only is seen. The prisms can be made

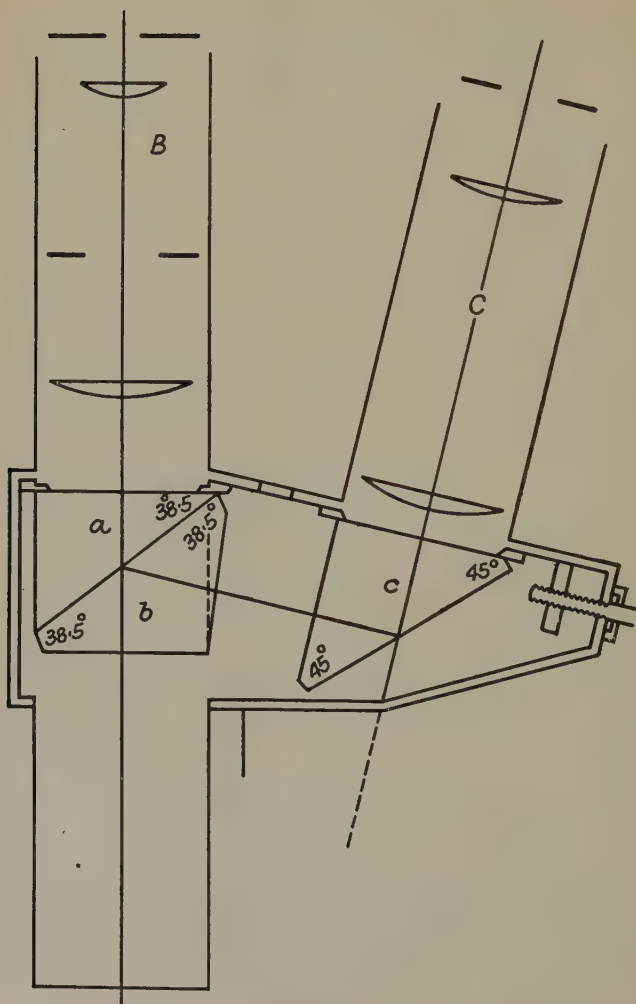


Fig. 135.

either of French plate or of a light crown glass, care being taken that the pieces used are free from defect. Fig. 135 will give a working drawing of it, the actual size for a short-body instrument. Fig. 136 shows an ordinary Huygenian eyepiece for a micrometer to drop in on the stop. The eye-lens is in an independent tube, so that it can be focussed sharp for exact adjust-

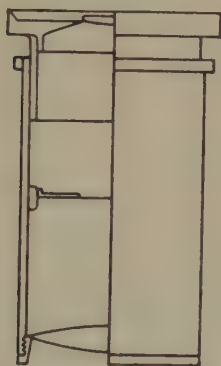


Fig. 136.



Fig. 137.

ment of the micrometer scale (Fig. 137) to the eye of the observer. For such exact measurements of objects which occupy a large portion of the field, and cannot be measured with sufficient accuracy by an ordinary micrometer eyepiece, a Ramsden can be constructed with a glass plate with cross lines, which are moved across the field by means of a fine screw, *A* (Fig. 138). Each interval of the divided drum (Fig. 139) corresponds to 0.002 millimetres of the image. Complete

revolutions of the drum are counted by means of a figured scale in the field on the glass plate. A $\frac{1}{4}$ in.

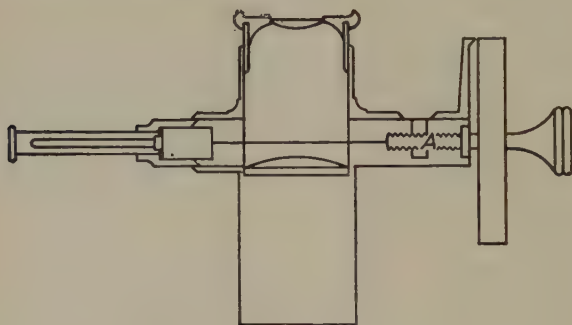


Fig. 138.

of object can be measured most accurately by one of these instruments.

Indicator in Eyepiece. Another addition to an eyepiece consists of an indicator for pointing to any par-

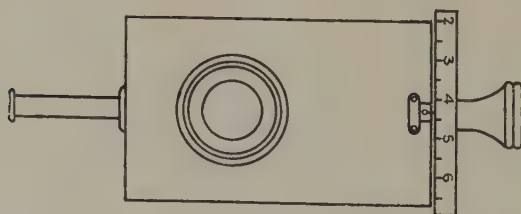


Fig. 139.

ticular point in an object under examination. This consists of a cylinder of small tube, fixed to a small

piece of brass, *A* (Fig. 140), and fitting in a socket on the top of the eyepiece; fitted on to the tube is a very fine needle, filed as fine as possible. This can reach

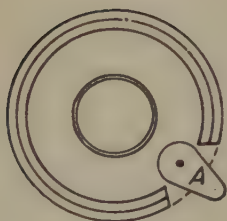


Fig. 140.

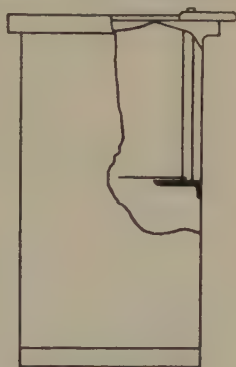


Fig. 141.

just the centre of the field, and will appear sharp and black if very close to the face of the stop. By its means any particular part of an object can be pointed

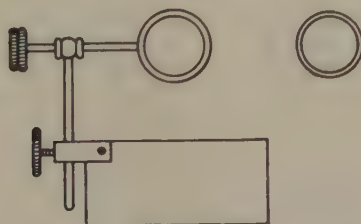


Fig. 142.

out to another observer. Fig. 141 will show the needle in position. A simple drawing instrument that can

easily be made is a Beale's camera lucida. It can be made either to fit round for a small eyepiece, as in Fig. 142, or to replace the cap of a best eyepiece, as in Fig. 143, which also shows the angle the glass must be



Fig. 143.

placed on the cap. It is convenient to have several shades ; the different pieces of neutral tint glass can be bought for a few pence.

CHAPTER XV

WOLLASTON CAMERA LUCIDA AND METHOD OF SETTING IT;
CAMERA LUCIDA OF TWO PRISMS; HEMISPHERICAL CON-
DENSER; SPOT LENSES; SMALL ACHROMATIC CONDENSER;
WEBSTER CONDENSER; ABBE CHROMATIC CONDENSER

IN the camera lucida invented by Wollaston, the essential feature is a quadrilateral prism, of which A, B, C, D (Fig. 144) represent a section at right angles to each of its edges; AB is equal to BC , and AD to DC , and the angles of the prism are a right-angle at

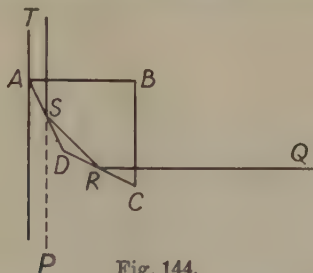


Fig. 144.

B , an angle of 135° at D , and angles each $67\frac{1}{2}^\circ$ at A and C . Over the face BA is a plate of metal, having in it a longitudinal aperture which is bisected by the edge A of the prism. The axis QR of a small pencil of light from the objective q , directly in front of the face

BC , passes straight through this face, and falls upon the face DC , making with it an angle of $22\frac{1}{2}^\circ$; it is there reflected into the direction RS , and falling upon the face DA at the same angle, is again reflected into the direction ST perpendicular to the face AB , and consequently passes straight through this face without refraction. Looking down through the aperture in the metal plate, an image of the object q is seen at P at a distance from AB equal to the distance of the

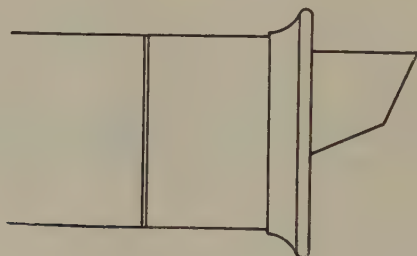


Fig. 145.

object itself from BC ; and if AB be placed at a distance from a table not less than the distance of distinct vision, and a sheet of paper be laid on the table at P , the image of the object as seen through the prism will be thrown on the paper seen through the projecting part of the aperture, and an accurate drawing of the object may be traced on the paper. Fig. 145 will show the prism in position on its cap, and Fig. 146 the manner of setting. The edge C (Fig. 144) of the prism must just cover the eye aperture of the cap.

Fig. 147 is a camera lucida of two prisms. These are fixed in a box independently over the eyepiece.

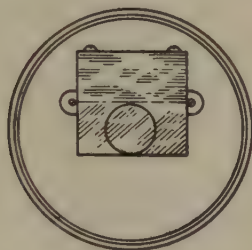


Fig. 146.

Camera Lucida with Single Reflection. Devices which reflect the pencils of light issuing from the eyepiece so that the image is projected upon a vertical or more or less inclined surface are more simple to make

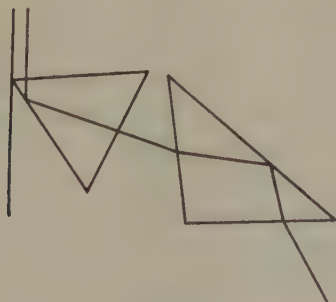


Fig. 147.

than devices which project the rays of light from the issuing pencil by two reflections, so that they appear

to come from points in the field of view. Here the microscopic image is seen directly through an aperture in the last reflecting surface, or near to it. This principle may, of course, be applied with various modifications similar to those of the preceding devices. The drawing surface is made visible by double reflection from a plane mirror, and from the silvered surface of a small prism in the eyepiece. The image to be drawn is seen directly through an aperture made in the silvering of the prism. By the concentricity thus obtained of the pencil of rays reaching the eye from both the microscope and the paper, the image and pencil are seen coincidently without straining the eye, and drawings may be made on a horizontal surface without perceptible distortion. With pencils of light projected upon a vertical or more or less inclined surface, the last reflecting surface is provided with a small aperture, as seen, so that the eye sees, through a portion of the pupil, the point of the pencil with which the outlines of the image are being traced. The pencil is therefore seen directly in this case, whilst the image of the microscope is seen by reflection. But since a single reflection involves a half-inversion of the image, those appliances are the most advantageous in which two reflections take place in the plane as the Wollaston camera-lucida prism, acting by two internal reflections.

Illuminating Apparatus. From eyepieces and apparatus used in conjunction with them we shall take in hand the condensers and other illuminating devices.

This part of lens-work is not so particular as the objectives and eyepieces. One of the simplest of condensers consists of a hemispherical lens (Fig. 148) that can be annexed to the back of a ground-glass slip by either water or oil, or it may be put on with Canada balsam. These hemispheres can be made to various curves, and are always handy, as well as being a good piece of practice in getting lenses to extreme curvature. The best way to get the curve up to the extreme edge is to have three or four tools (pairs of), the first you use being rather shallower than the curve that is required, so that you can gradually bring the lens up by the tools being deeper as you proceed, and



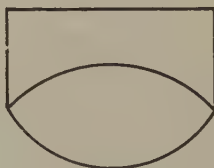
Fig. 148.

this method will enable you to get the edges up, which would otherwise be rather difficult. Your runner must, of course, be cut away from the back very much to allow you to get a sufficient sweep. All condensers have deep curves to get sufficient angle, and in making others you will know how to proceed. The next simplest lens for dark-ground illumination is the spot lens. This can be made from any glass that is clean. Get a piece of glass, and turn it up to a curve you think you would require (the shorter or deeper the curve, the closer to the object it will be required to go; and the longer or

shallower the curve, the farther from the object); leave a flat spot on the convex side, as shown in Fig. 149; work and polish the curve. Before you take the lens off its runner, get a piece of copper and some fine emery and nicely grey the spot. Now put the lens on a hollow runner, and turn a concave spot out on the plane side to the same size that you have left the spot on the convex side, and emery out any little



Fig. 149.



2 -
3 +
4 +

Fig. 150.

splinters that may appear on the edge of the flat surface till the hollow looks quite sharp. Put a chamfer on the edge of the flat and a coating of black wax in the hollow, and the lens is (after cleaning off) ready either to go in a tube for the stage fitting or a piece of apparatus for the substage. A simple achromatic condenser is made from Chance's dense 3.65 flint and French plate glass (Fig. 150). This is a simple combination, and the working is as follows:—

Surface.	+ - .				Template.			
1 . . .	Plano				.	.	.	—
2 . . .	.	.	.	.	.	.	.	·7
3 . . .	+	.	.	.	.	.	.	·7
4 . . .	+	.	.	.	.	.	.	·6
Diameter . . .	.	.	.	.	.	.	.	·5

Crown feather-edge at ·5. Substance of flint half the substance of crown in the centre :—Glass, Chance's H.F. and French plate.

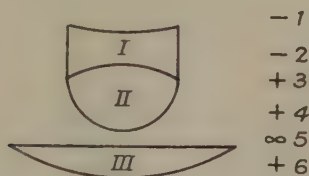


Fig. 151.

In all combinations where you use French plate with Chance's dense flint, you will require to have the lens (the double convex) double, and with some curves triple, the thickness of the flint, whereas if you use Chance's hard crown the proportion is nearer equal. One thing that French plate is advantageous for in a condenser is that, having to be so thick, you can get a greater amount of curve than if you used a denser crown. The Webster condenser (Fig. 151) is also made of H.F. and French plate, with the addition of a field-lens, and the working data are as follows :—

Surface.	+ -		Template.
1	-	.	10.0
2	-	.	1.2
3	+	.	1.2
4	+	.	.6
5	Plano		
6	+	.	2.5
Diameter	.	.	.6

Substance of flint half the substance of crown in centre:—Glass I, Chance's dense F., 365; Glass II., French plate; Glass III., French plate.

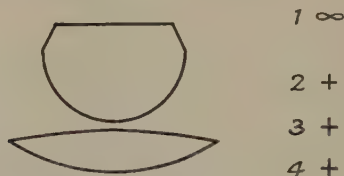


Fig. 152.

The ordinary Abbe condenser is a very simple one to make (Fig. 152). It is composed of either crown or plate glass. The following are the working data:—

Surface.	+ -		Template.
1	Plano		
2	+	.	.722
3	.	.	6.5
4	.	.	1.8
Diameter of front	.	.	.7
Diameter of back	.	.	1.1 sharp edge
Thickness of front lens	.	.	.5

CHAPTER XVI

LARGE ANGLE ABBE ILLUMINATOR; ACHROMATIC ILLUMINATOR;
STOPS USED FOR DARK GROUND ILLUMINATION; HALF-ARC
ILLUMINATOR; THE PARABOLOID

THE wide-angle condenser (Fig. 153), with an iris diaphragm fitted to it, is about the best that can be used for all-round work. This can also be constructed

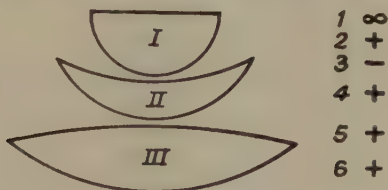


Fig. 153.

from common glass, and the curves required to get the extreme amount of light are as follows:—

Surface.									Template.
1	Plano								
2	+	.	.	.	.	.	.	.41	
3	—	.	.	.	.	.	.	1.8	
4	+	.	.	.	.	.	.	.9	
5	+	.	.	.	.	.	.	5.	
6	+	.	.	.	.	.	.	1.9	
Diameter.									
I.	.	.	.	.	.	.	.	.4	
II.	.	.	.	.	.	.	.	.83	
III.	.	.	.	.	.	.	.	1.2	

These are mounted so that, looking from the posterior lens, the observer sees a clear aperture; that is, the front looks exactly the same size as the posterior lens when looking from the back of the setting. The essential feature of this condenser of short focus is, it collects the light reflected by the mirror into a cone of rays of very large aperture, and projects it on the object. The full aperture of the illuminating cone

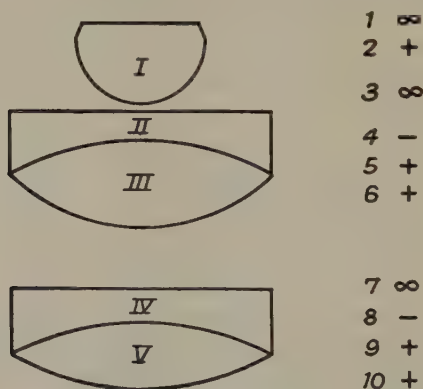


Fig. 154.

should only be used when finely granular and deeply stained objects are being examined with objectives of large aperture. In every other case the cone must be reduced to suitable dimensions, either by the iris diaphragm or an ordinary wheel diaphragm. On placing the diaphragm out of centre, the central rays are excluded; and a certain extra-axial portion of the illuminating pencils falls obliquely upon the object, and with

a central stop diaphragm it shuts off all the axial, and transmits only the marginal, rays for dark-ground illumination.

Achromatic Condenser. Next we get to an achromatic condenser corrected as well as an objective for visual use. This is $\cdot 9$ numerical aperture, and is especially adapted for photo-micrography. Fig. 154 is the section, and the following are the working data :—

Surface.		Template.
1	Plano	
2	+	$\cdot 48$
3	Plano	
4	—	$2\cdot 2$
5	+	$2\cdot 2$
6	+	$1\cdot 5$
7	Plano	
8	—	$2\cdot 6$
9	+	$2\cdot 6$
10	+	$1\cdot 8$
Lens.	Substance.	Diameter.
I. . . .	$\cdot 34$	$\cdot 475$
II. . . .	$\cdot 1$	$1\cdot 08$
III. . . .	$\cdot 34$	$1\cdot 08$
IV. . . .	$\cdot 14$	$1\cdot 08$
V. . . .	$\cdot 34$	$1\cdot 08$

The glass to make this condenser should be the flint of $3\cdot 60$ density and the crown of $2\cdot 49$; but if you use Chance's flint ($3\cdot 65$), you should place the back combination rather closer to the middle, which will counter-act somewhat the extra density of the flint. Figs. 155,

156, and 157 show stops that can be used with any of the condensers that have been worked out here. These can be filed out of small discs of metal. Another small illuminator is the semi-disc; these, of course,



Fig. 155.

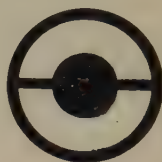


Fig. 156.

have to be made in pairs. The plano surfaces are first worked, and then stuck together with either shellac or black wax. Next they are ground parallel, and then stuck on to a runner in the lathe, care being taken to have a central mark on the runner that the division cuts exactly across. It is safest to grind the curve on the edge by means of emery, and not to turn them up either with file or diamond, as you may be liable to



Fig. 157.



Fig. 158.

splinter the flat surfaces, notwithstanding that the two surfaces are cemented as close together as they can possibly be. The edge is ground and polished to a curve of $\cdot 2$. Fig. 158 shows a pair of them finished,

ready for uncementing, and a section of one to be mounted as in Fig. 159.

The Paraboloid. Next we come to the paraboloid, which is rather a difficult job for an amateur to do. Fig. 160 is a section of the paraboloid, actual size; C is the base, and AB are the parabolic sides of the section, the apex being cut off to make a passage for



Fig. 159.

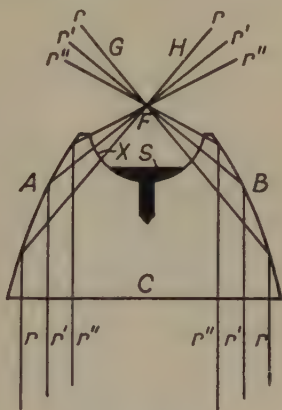


Fig. 160.

the rays of light, $r' r'' r'''$, to the object, and a stop, S , being placed in the aperture thus formed by grinding out the curve X to prevent any rays from passing direct to the objectives. The light is thrown upon the parabolic surfaces A and B in rays parallel to the axis of the parabola, and will thus be reflected to the focus F of the parabola, which must be adjusted to the object in view. The objective lying entirely within the

angular space $G F H$, which admits no rays direct from the reflector, can therefore receive only the rays irregularly reflected from the object. First, strike out a

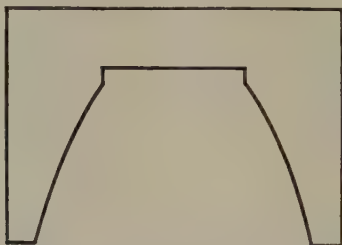


Fig. 161.

parabola on a thin piece of sheet-steel, as in Fig. 161; when perfect, this should be hardened and tempered. Now get a piece of plate or crown glass of sufficient thickness; work the plano surface, and then stick it

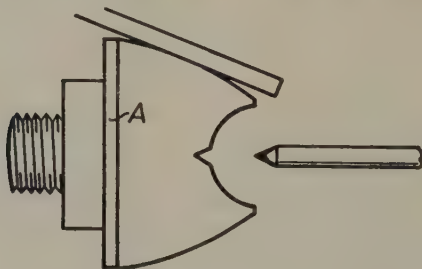


Fig. 162.

on to a piece of thin plate glass (A of Fig. 162). If you have got an old grindstone, you might grind it up to somewhere near the shape on that; but you will do it

more quickly if you use a very slow speed and a few very hard files ground up as described before. Keep trying it to the gauge, and when nearly up you can roughly turn the spherical curve out, which should be to template '6. Now get a flat piece of brass and grind a hollow in it—a small one at the start, so that it will rest on the curve of a parabola, and proceed to emery the parabola up, working the piece of brass from the apex to the base. You will soon find that it will get

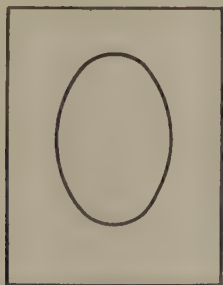


Fig. 163.

to the curve, making an oval on the brass, as in Fig. 163. You can get the glass quite to the curve with this tool only, and also emery it quite fine. You must not let it stop anywhere, but keep working it backwards and forwards, or you will have your curve ring, and the cuts are liable to be very deep. Now you want to drill a hole for the stop to go in. First, get a piece of square drill steel of suitable size, and file each of the sides to a point; this will give you four cutting sur-

faces; next, harden it as hard as you can by heating to a bright red and plunging into cold water to which is added a little salt; they do not want any tempering—the harder the better. Now grind the four surfaces sharp, make a rest of your T in front of the lens, and drill the hole. Directly the drill gets dull, sharpen again; turps should be used as the lubricant whilst drilling, and if you are careful, a nice clean hole is the result. Now we can grind up the spherical curve and polish it.

Polishing a Parabola. To make a polisher for the parabolic surface, you can stick one in the brass you used for grinding, or polish the lens on a bob having a ring in it. This is a very pretty job when finished, and well worth any one's time and trouble. The parabola is also made with a flat end where the $\cdot 6$ curve is, and they are also drilled right through the centre, so that the stop can be pushed up to cut off certain rays.

When drilling the hole quite through the parabola, care should be taken, when nearly through, not to splinter the flat surface by pushing too hard on the drill. If the hole shows rough through the polished surface by the drill cutting rank, you can grind the hole smooth by a piece of copper wire and some fine emery.

CHAPTER XVII

ILLUMINATION

WHEN it is required to illuminate a portion of an object on the field of the microscope with a single pure spectral colour, or to observe the whole spectrum upon it, or, finally, to study the effects of the spectrum of polarised light, the following systems of prisms and lenses can be used.

Illuminating with Monochromatic Light. For illuminating for monochromatic light (Fig. 164), the light which emerges from a slit at *A* is rendered parallel by means of a pair of lenses, *B*; it is then spectrally decomposed, and projected upon the specimen under observation by means of a pair of lenses at *C*. The spectrum will be sufficiently extended to ensure approximately uniform monochromatic illumination with higher powers. By adjusting the position of the slit by means of a right and left-hand screw at *A*, the various colours of the spectrum may be made to traverse the whole of the vision.

Spectro-polariser. Fig. 165 is a complicated spectro-polariser; but as it comes under the heading of illuminating apparatus, it may as well be described. This instrument was designed for determining the character

of double refraction in microscopical specimens for particular wave-lengths. A combination of two flint-glass prisms arranged to produce a deviation of 90°, have on one side a movable slit, *A*, and a collimator lens, *B*, on the other side, at *C* is a microscope objective, which from below projects a real spectrum on the specimen under observation. Between *D* and *E* is a

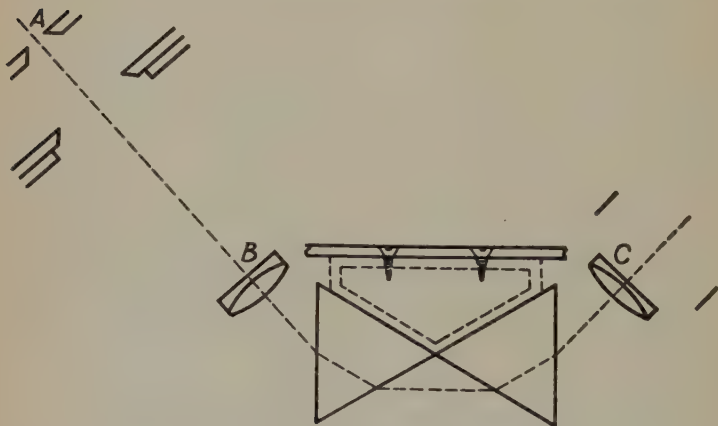


Fig. 164.

tube on the prism casing with the mirror *M* attached, a pair of lenses, *D*, and a scale divided and numbered according to the wave-lengths. By reflection from one surface of the prism a real image of this scale is projected, together with the spectrum, into the plane of the object. The edges of the slit *A* are made to move symmetrically by a right and left-hand screw, so that

the centre of the split shall remain central and station-

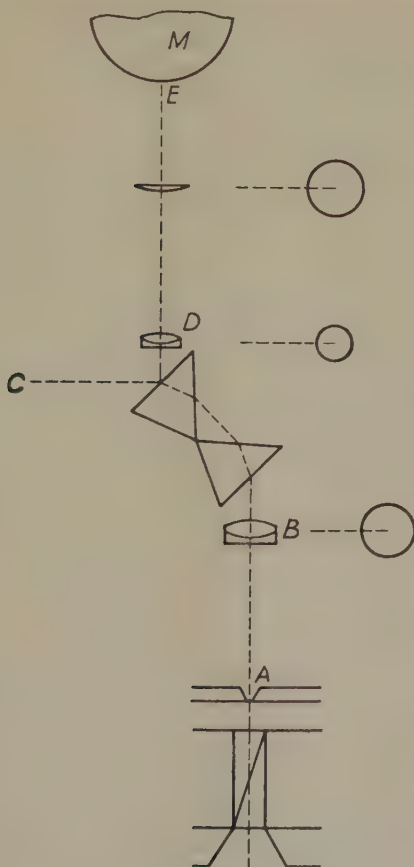


Fig. 165.

ary. A prism mounted below on a gimbal that can

swing away in front of the slit serves as a polariser, and between that and the slit selenite films can be placed for producing interference lines in the spectrum. Low-power objectives can be used to project a spectrum of any desired dimensions.

Lantern Condensers. A quite simple piece of work, affording good practice in working to a tolerably large size, is making a compound plano-convex condenser for lantern projection or photographic enlarging. A 4-in. diameter condenser consists of two plano-convex lenses, each of 5-in. focus. The curve, therefore, is of $2\frac{1}{2}$ -in. radius. The lenses are mounted loosely to allow for heat expansion, with their convex sides almost touching.

CHAPTER XVIII

SIMPLE MICROSCOPES, ACHROMATIC POCKET MAGNIFIERS, ETC.

MAGNIFIERS are very simple jobs. The first I shall describe will be the Coddington. Harting, in his "History of the Microscope," says that Brewster was the first to hit upon the happy idea of making a groove in a glass sphere for a magnifying glass (Fig. 166)* which gives images approximately free from aberration. Coddington facilitated their production by giving the groove the angular form of Fig. 167, making the two halves of the sphere separately out of suitable pieces of plano-convex lenses which were afterwards

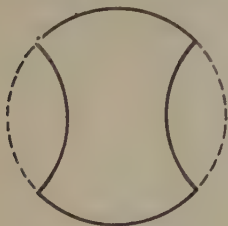


Fig. 166.



Fig. 167.

cemented together at the plano surfaces. The shape of the groove is of no consequence, as the construction represented in Fig. 168 answers the purpose as well as the previous ones.

* Figs. 166 to 178 are double actual size.

The Coddington Lens. These lenses can be made to give upwards of twenty linear magnification. However, they are defective in two ways which are important



Fig. 168.

in many researches: the field of view is very limited, and the distance of the focus from the lower surface is about a quarter of the diameter of the sphere. When it is required to observe an object of rather large dimensions, which is the most frequent case in practice, a modern combination of lenses that is aplanatic is far preferable. Get a piece of plate glass of sufficient

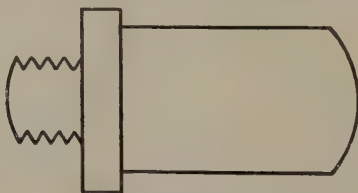


Fig. 169.

thickness, shank it round, and cement it on to a flat runner; turn the edge to its proper size, and the spherical curve to whatever diameter it has been determined

to have (Fig. 169). The thickness of the lens will, of course, depend on the curve, for it must be borne in mind that it would be a perfect sphere if the curve

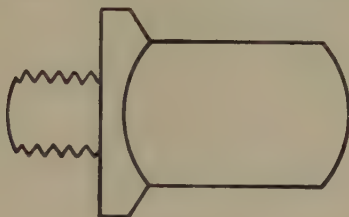


Fig. 170.

were continued, so that if the curve be $\cdot 6$ diameter, the thickness of the lens will be $\cdot 6$. When the curve has been emieried and polished, it is taken off the flat runner and cemented on to a concave one, and the opposite side worked, when, if a section were taken, it would appear as Fig. 170.

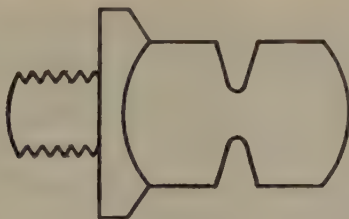


Fig. 172.

Cutting a Groove to Form a Stop. Now whilst the lens is on the runner the groove can be cut that is to make the image sharp. This can be done by turning

the groove out with a diamond, but great care must be taken when you get near the centre, for at this stage they have a nasty habit of parting when very nearly finished. A very good way, when about a third down, is to finish with a piece of copper wire bent to suitable shape, and fed with emery till the stop has the desired diameter. Fig. 172 shows the magnifier finished ready for taking off the chuck. If you let the flame of the spirit-lamp touch the centre of the lens, it is liable to split.

Plano-convex Lenses with a Metal Stop. Another way to make a magnifier very like the Coddington is



Fig. 173.

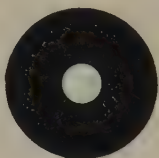


Fig. 174.

to grind two plano-convex lenses like Fig. 173, with the stop shown in the figure between them. This acts just the same as a solid lens, if the lenses are placed as in Fig. 174. All these can be mounted in tubes, and are very handy to carry about. With those just mentioned are closely connected the cylinder magnifiers which have long been used. These consist of a cylinder of glass similar to the Coddington, but the two surfaces of which are ground convex, and are of unequal curvatures to diminish the aberration (Fig. 175). The shallower curve is usually directed to the object. These lenses

produce less perfect images than the Coddington, and are accompanied with the similar disadvantage of a short focal distance; nevertheless, they must be classed among the least costly and most effective of magnifiers. If the stronger curve is turned towards the object in view, a greater focal distance is obtained, but the aberrations are more noticeable, and consequently the image less distinct. The one drawn in Fig. 175 is in the proportion of two to one. Of course any two curves can be used that the maker may fancy.



Fig. 175.

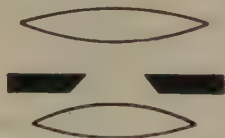


Fig. 176.

The Wollaston Doublet. Another ordinary and more powerful magnifier is shown in Fig. 176. This consists of two double-convex lenses, with a diaphragm between them. These magnifiers can be made to almost any power, and also by triples, and mounted so that one can be made to swing away from the other, so getting several different powers. Systems composed of two or three plano-convex lenses, the so-called doublets and triplets, are always very useful for dissecting purposes. Nageli and Schwendener say that it is true that earlier optical physicists, especially Euler

and John Herschel, had already occupied themselves in developing such combinations of lenses; but with the impossibility of satisfying the results of calculation in the grinding of the lenses, the theoretically accurate purposes were of little practical importance.

Separation of Lenses and their Sharpness. Wollaston was the first to discover a means of increasing the sharpness of the image by the relative distance of the lenses determined by experiment, rather than by their particular form. His doublets consist of two plano-convex lenses with the plane surfaces turned downwards,



Fig. 177.

their focal lengths in the ratio of about 3 to 1, and placed one above the other in such a manner that the distance of the plane surfaces is about 1.5 of the shorter focal length (Fig. 177). The success of these doublets and the attention which they aroused soon led to further improvements, which have culminated in the production of the exquisite lenses now in use. Pritchard found the most favourable distance of the two lenses to be equal to the difference of their focal lengths, but that these focal lengths might vary within certain limits between 1.3 and 1.6. He con-

structed doublets which were remarkable for the clearness and sharpness of the image up to an amplification of two hundred linear, and of which the low-power ones are very well adapted for dissections.

Nachet's Doublet. Another doublet is constructed of two plano-convex lenses of equal focal length, but of unequal size (Fig. 178), so that the larger is nearest the object; between the two is placed a diaphragm. A considerable intensity of light is thus obtained, and at the same time a greater distance of the object from the



Fig. 178.

first refracting surface. In order to make these magnifiers or dissecting objectives, the three-to-one system is practical enough; but, as with the eyepieces, to get a particular power at its best the curves are altered as wanted. Thus for a one-twentieth doublet the working directions would be as follows:—

Radius	+	.	.	.	·0666
					Plano; nearly hemispherical
	+	.	.	.	·025
					Plano; hemisphere

made of any crown or plate glass.

CHAPTER XIX

CURVES FOR MAGNIFIERS AND MICROSCOPE OBJECTIVES

A SERIES of achromatic magnifiers can be made of Chance's heavy flint and hard crown; they have a fair working distance, and do not require a stop.

No. 1.	+	.	.	.	.	.	1.8	Template
	+	.	.	.	.	.	1.8	
	-	.	.	.	.	.	1.8	
	Plano							
	Diameter						.72	
	Substance of crown						.15	
		"		"	flint		.15	
No. 2.	+	.	.	.	.	.	.152	Template
	+	.	.	.	.	.	.152	
	-	.	.	.	.	.	.152	
	Plano							
	Diameter						.5	
	Substance of crown						.1	
		"		"	flint		.1	
No. 3.	+	.	.	.	.	.	.12	Template
	+	.	.	.	.	.	.12	
	-	.	.	.	.	.	.12	
	Plano							
	Diameter						.48	
	Substance of flint						.095	
		"		"	crown		.095	

No. 4.	+	.	.	.	.	.	.	·9	Template
	+	.	.	.	.	.	.	·9	
	—	.	.	.	.	.	.	·9	
Plano									
	Diameter.							·36	
	Substance of flint							·075	
							„ „ crown	·075	
No. 5.	+	.	.	.	.	.	.	·6	Template
	+	.	.	.	.	.	.	·6	
	—	.	.	.	.	.	.	·6	
Plano									
	Diameter.							·24	
	Substance of flint							·05	
							„ „ crown	·05	
No. 6.	+	.	.	.	.	.	.	·45	Template
	+	.	.	.	.	.	.	·45	
	—	.	.	.	.	.	.	·45	
Plano									
	Diameter.							·18	
	Substance of flint							·0375	
							„ „ crown	·0375	
No. 7.	+	.	.	.	.	.	.	·3	Template
	+	.	.	.	.	.	.	·3	
	—	.	.	.	.	.	.	·3	
Plano									
	Diameter.							·14	
	Substance of flint							·025	
							„ „ crown	·025	

These will be as shallow or as deep as any one would want to go for a magnifier; but if wanted to make pairs of them, they will all work one with the other. For instance, the pair of No. 2 and No. 4 put at a suitable distance would make a lens of about $1\frac{1}{3}$ in. focus. Any of these pairs are far superior to the

doublet or triplet systems for dissecting purposes, as well as being a basis for all shallow-power microscope objectives.

Triple Achromatic Magnifiers. Two handy triple systems that can be used either as objectives or magnifiers are as follows, only to get sufficient sharpness they must be stopped down somewhat :—

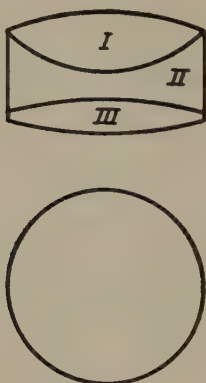


Fig. 179.

Fig. 179. No. 1 + ·14 Template

	+·7	"
	-·7	"
	-·20	"
	+·20	"
	+·28	"
	Diameter ·5	"
No. 1. Substance	·175	1. Glass, French plate
No. 2. "	·07	2. " Chance's light flint
No. 3. "	·08	3. " French plate

The above gives an amplification equal to a $1\frac{1}{2}$ in. microscope power.

Fig. 180. No. 2+·106 Template

	+·048	"
	-·048	"
	-·20	"
	+·20	"
	+·20	"
Diameter	·38	"
No. 1. Substance	·13	1. Glass, French plate
No. 2. "	·04	2. " Chance's light flint
No. 3. "	·065	3. " French plate

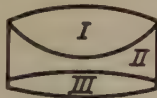


Fig. 180.

Curves for microscope objectives are as follows. If properly made they will be found equal to any:—

	3in. Objective.				
Back combination	+	.	.	.	3·6 Template
	+	.	.	.	3·6
	-	.	.	.	3·6
					Plano
Substance of crown	.	.	.	.	·27
" " flint	.	.	.	.	·27
Diameter	.	.	.	.	·7

3in. Objective.					
Front combination	+	.	.	2.7	Template
	+	.	.	2.7	
	-	.	.	2.7	
Plano					
Substance of crown	.	.	.	.225	
" " flint	.	.	.	.225	
Diameter	.	.	.	.5	
Distance from plano of front to plano of back	.	.	.	1.8	
2in. Objective.					
Back combination	+	.	.	2.4	Template
	+	.	.	2.4	
	-	.	.	2.4	
Plano					
Substance of crown	.	.	.	.19	
" " flint	.	.	.	.19	
Diameter	.	.	.	.65	
Front combination	+	.	.	1.8	Template
	+	.	.	1.8	
	-	.	.	1.8	
Plano					
Substance of crown	.	.	.	.15	
" " flint	.	.	.	.15	
Diameter of front	.	.	.	.5	
Distance from plano of front to plano of back	.	.	.	1.5	
1½in. Objective.					
Back combination	+	.	.	1.8	Template
	+	.	.	1.8	
	-	.	.	1.8	
Plano					
Substance of crown	.	.	.	.142	
" " flint	.	.	.	.142	
Diameter	.	.	.	.6	
Front combination	+	.	.	1.35	Template
	+	.	.	1.35	
	-	.	.	1.35	

1½in. Objective.

Plano

Substance of crown	.	.	.	.	·114
" " flint	.	.	.	.	·114
Diameter	.	.	.	.	·45
Distance from plano of front to plano of back	.	.	.	.	1·3

1in. Objective.

Back combination	+	.	.	.	1·2	Template
	+	.	.	.	1·2	
	-	.	.	.	1·2	

Plano

Substance of crown	.	.	.	.	·095	
" " flint	.	.	.	.	·095	
Diameter	.	.	.	.	·45	Template
Front combination	+	.	.	.	·9	
	+	.	.	.	·9	
	-	.	.	.	·9	

Plano

Substance of crown	.	.	.	.	·075
" " flint	.	.	.	.	·075
Diameter	.	.	.	.	·036
Distance from plano of front to plano of back	.	.	.	.	1·1

¾in. Objective.

Back combination	+	.	.	.	·8	Template
	+	.	.	.	·8	
	-	.	.	.	·8	

Plano

Substance of crown	.	.	.	.	·06	
" " flint	.	.	.	.	·06	
Diameter	.	.	.	.	·35	
Front combination	+	.	.	.	·6	Template
	+	.	.	.	·6	
	-	.	.	.	·6	

$\frac{1}{2}$ in. Objective.				
Plano				
Substance of crown	.	.	.	.05
" " flint	.	.	.	.05
Diameter	.	.	.	.24
Distance from front plano to back				
plano	.	.	.	.7
$\frac{1}{2}$ in. Objective.				
Back combination	+	.	.	.6
	+	.	.	.6
	-	.	.	.6
Plano				
Substance of flint.	.	.	.	.05
" " crown	.	.	.	.05
Diameter	.	.	.	.24
Front combination	+	.	.	.45
	+	.	.	.45
	-	.	.	.45
Plano				
Substance of flint.	.	.	.	.0375
" " crown	.	.	.	.0375
Diameter	.	.	.	.18
Distance of front plano to back	.	.	.	.5

These curves will be amply sufficient, and the $\frac{1}{2}$ in. is quite as deep as it is advisable to go. If made to the data given, the lenses will be perfect, and you can have the shoulders of the settings as small as convenient, as these systems *do not require a stop*.

CHAPTER XX

WORKING FLAT AND SHALLOW SPHERICAL SURFACES

Working Planes. Flat and prism work require a good deal of practice to become perfect at it; but, with the aid of a few diagrams, I shall endeavour to make it as straight sailing as possible. To get a perfect flat we shall require three tools, or if a piece of plate glass has to be worked so, can dispense with tools altogether. Say we want to work a disc 10in. across. The best way is to get three discs, and number them No. 1, No. 2, and No. 3. We can afford to do this, as the glass is not very costly. After they have all been shanked to a size, we begin emerying. Four pieces of cork should be screwed to the bench at such a distance that the discs can rest in them so as not to move, but so that they can be easily taken off. Put No. 1 on the bench, and proceed to give it an emery, using No. 2 on top of it when the emery is worked down. Put No. 2 on to the bench, and work over No. 3. Then put No. 3 on the bench, and work over it No. 1, and by that means you will get a perfect flat.

Three Discs to Get a Perfect Plane. When they are clean and of the required fineness, as perfect as it is possible, they can be polished; but as you are just as

liable to get the surface all sorts of shapes over that operation, we must devote a little space to it. But here I want to show how the stroke influences the surface in the emerying. We shall suppose we have

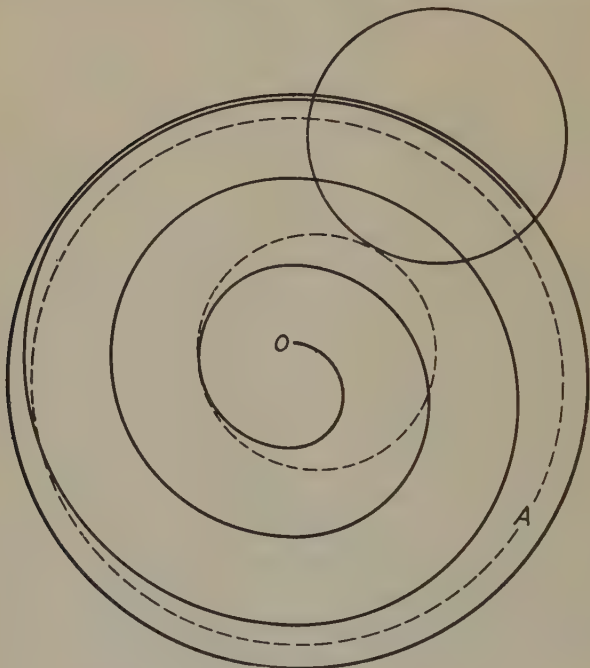


Fig. 181.

as perfect a flat tool as it is possible to get, and want to emery a piece of glass or a number of pieces arranged on a runner. First get a little emery on the end of the finger, and dab it over the tool. Next get a

bruiser—that is, a piece of flat glass to first work the emery over the flat tool to take off the superfluous emery and carry to the edge any grit that may be among it.



Fig. 182.

To do this properly, you put your bruiser on the tool at *O*, and bring it towards the edge in an ever-increasing circle, as shown in Fig. 181. When it is at

the edge, as shown, it should be carefully lifted off, and the edge of the tool wiped with a very clean sponge to the depth on the tool as shown in the figure by the dotted line *A*. The emery should now be uniformly spread over the tool, and the proper piece of work put on that has to be emiered. Being put on, it should be moved over the tool by long, uniform strokes over every part of it as symmetrical as possible, following the lines as in Fig. 182, and at the same time moving the block itself round after every two or three strokes. If the tool is revolving, there would also be a motion from the centre of the tool, as shown in Fig. 183; and I shall now proceed to show the effect of this and other strokes on the piece of glass to be emiered.

We have a tool as perfect as we can get it, and want to emery a piece of glass for an example. This piece of glass is rather thin, so it has been put on to a runner that has a wooden handle, that can be screwed on and off by means of pitch pellets. Now, if these pellets are deep enough, or the glass has not been pushed home too much, there will be sufficient space between the runner and the glass to give free use of the calipers to measure the piece of glass for parallelism. The object of this will be seen later on. If we put some emery on the tool and bruise it over, we can put the piece of glass on, and proceed to work it over the tool; we do this indiscriminately, holding it in one position and working it about the tool. If measured when it is taken off, it will be found to be

wedge-shaped—that is, the part that the hand has rested most heavily on is found to be ground away

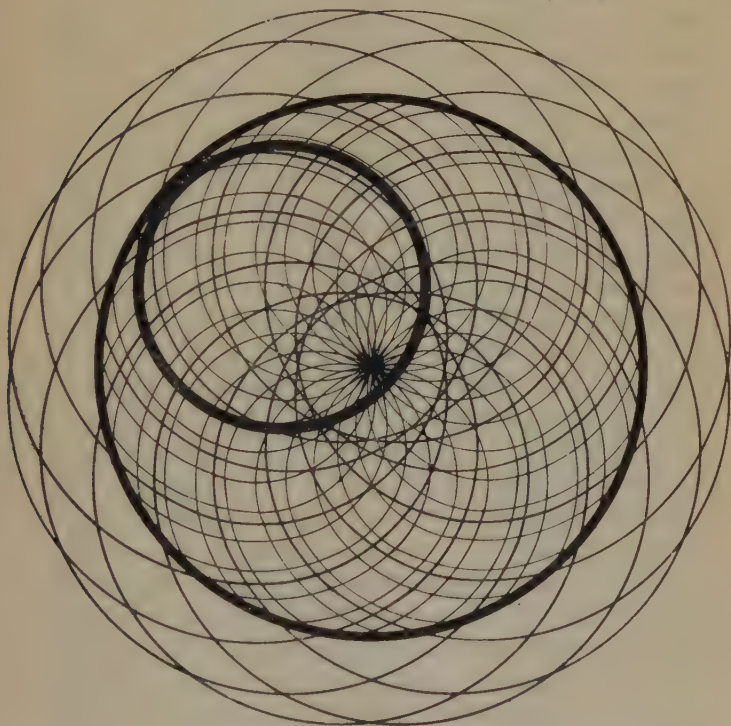


Fig. 183.

more than the opposite side, and if it has not been worked all over the tool, the edge that has had the

longest sweep will be thinner than the other, assuming that it was approximately parallel when started with.

To Keep the Disc Parallel. If we were to go on like this, our piece of glass would be of a sorry shape after a few emeries, so the first thing to be done is to continually keep the piece of glass or the block that you are working revolving. You will be able to keep on emerying as long as you like, and your piece of glass will keep parallel as regards trying by caliper at the edges; but how about the surface—is it flat? Not a bit of it. The coarser grains of emery work to the edge of the tool, and leave the finer ones in the centre, and it stands to reason that your glass will be a trifle convex. Of course, that cannot be allowed, so one way to obviate this evil to a certain extent is, when the emery is half-way worked down, you take the glass off, and, with a clean sponge, wipe the outside edge of the tool, about $\frac{1}{2}$ in. deep, perfectly clean of all emery; then, putting your glass on again, continue the process. You can repeat the edge-wiping process, if the emery is not too far gone, a second time. In this way the emery on the tool is gradually got to a finer and more homogeneous powder than is possible by merely working the emery down without taking the coarsest from the edge from time to time. By this means the surface will be flat enough for all practical purposes. If the tool revolves, the emery meeting the sweep of the block, a good amount of it is carried back towards the centre, so that the emery on the tool that is in work is more homogeneous than it

would be if it was on a tool that was rigid for the reason stated above.

Working the Plane. Suppose we have a piece of glass on a runner with a wooden handle, the glass put

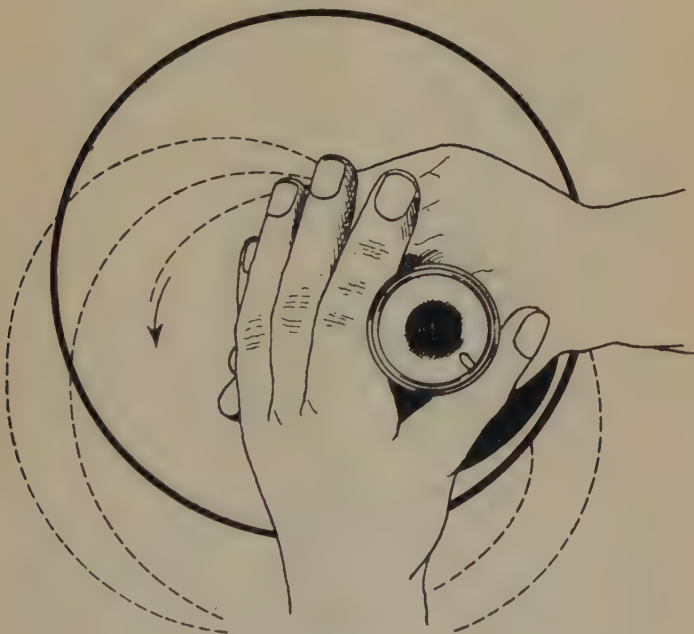


Fig. 184.

on, as before described, with pitch pellets. When we start, it is pretty parallel; but as we are not working it for parallel, but only for its surface, we shall only occasionally refer to its substance, and that will only

be for verification of the above statements. First, get some emery, and place a little on the tool in different parts, and proceed to bruise it. Get the bruiser, and see that it is perfectly clean; put it on the tool, and rub it

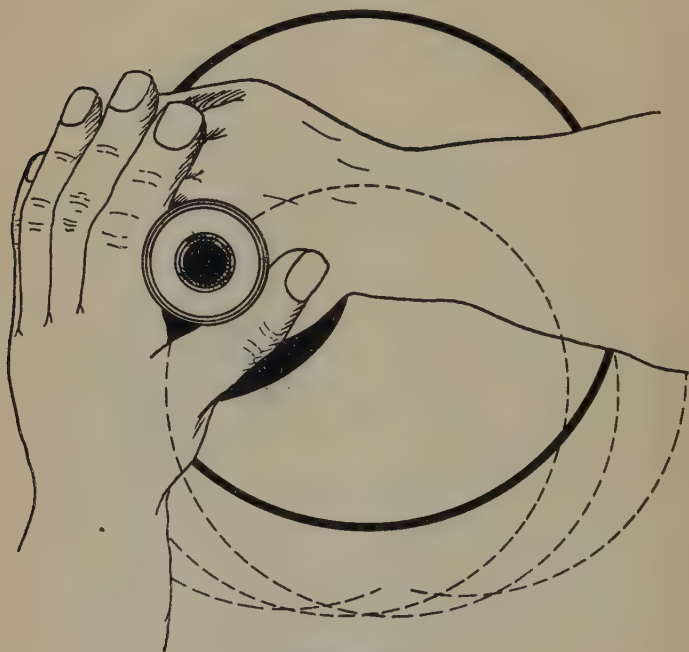


Fig. 185.

about to distribute the emery pretty evenly; when all over the tool, put the bruiser in the centre, and gradually bring it to the edge in the ever-increasing circle, as shown in Fig. 181, and then take about $\frac{1}{2}$ in. of the

emery from the edge of the tool. Now get the glass to be emiered, and having distributed a fine spray of saliva over it, lay it gently on the tool, and give it a rub and a slight twist round, to see if it is properly down on the tool, and no foreign substance in between. If right, move the block to the position shown in Fig. 184; lay the right hand on the runner, the wooden handle of it being between the thumb and the first finger. Now lay the left

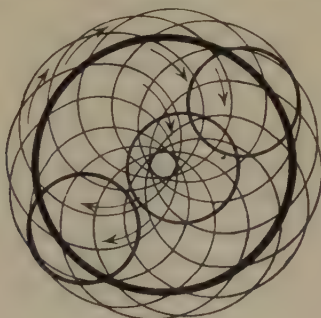


Fig. 186.

hand on top of it, as shown, and take a sweep round, following the dotted lines. After about two or three circles have been finished, raise the left hand from off the right, and with a movement of the fingers of the right hand move the runner round to the right, and replace the left hand. Now, if we look to the relative positions of the runner at Fig. 184 and Fig. 185, we shall find that whilst continuing the circles of Fig. 184 and Fig. 185 the block or piece of glass

has made a half-turn. If we continue moving the runner, every time we make three or four strokes we shall find that our runner has turned several times during the series of strokes that has been made to go completely round the tool. You will see exactly what I mean by referring to Fig. 186, which shows the block in three positions, as it will be if these directions are accurately followed.

Parallelism Kept by Constant Revolution. You will see by this method that if even the hand does rest heavily on one side, it is entirely obviated by the constant revolution of the runner. This is the circular sweeping stroke. But, to keep the tool and glass perfectly flat without the aid of others for connectors, the block or lens should be one-third the diameter of the tool it is being worked on. When the blocks or glass are of different sizes, and do not approximately follow this rule, then the intelligence and practical capability of the workman come in, and it is almost by instinct that he will alter the stroke to suit the requirements of the lens, and he will know his stroke directly his eye has taken the proportions of the block to the tool.

Humidity of the Emery. While we are looking after the stroke, we must also look to the condition of our emery on the tool, for with the final success of the operation this has a lot to do. Whilst working, it must be kept to a certain humidity; and as clean water will not always mix readily enough, resort is usually made to saliva, as by this means a fine spray can be put on to any part of the tool that seems to the

workman to be getting too dry. Sometimes it is impossible to keep on, on account of the saliva being insufficient to keep a large tool moist, so many workmen have recourse to tobacco to increase its flow. After a few complete revolutions you will notice the emery is darker, for it is getting mixed with the glass that is being ground off the lens, and the iron or brass that is being ground off the tool, and also the block seems harder to push. After a little time the emery assumes a greasy-black appearance; then the lens can be lifted off, and the edge of the tool wiped about $\frac{1}{2}$ in. from the edge. Now with a clean bruiser work the emery over the tool again, and finish working your block; but do not let the emery get too dry when finishing off, or the glass will suck, and you will have a difficulty to remove it from the tool, but have it humid enough to be just able to slide it off. This is, of course, only a description of one emery; but it is always best to treat all emeries like this, even with the fine truing, as by this way each emery is thoroughly worked down before a finer one is introduced, so that when giving the final emery you can be sure that the lens or piece of glass is well bottomed—that is, it has a truly fine surface, and not a surface that has been “blinded” by a fine emery, filling up the holes of a coarser one, only to be shown up directly the polisher begins to take, to the mortification of the operator.

Machinery cannot supplant Manual Labour. These are general instructions for smoothing all work, not only flat, but shallow curves, such as specula, etc. I

have seen some elaborate machines constructed to try and do away with hand labour for this class of work ; but a great deal to do with the failures has been the incapability of the machine to keep the emery at the proper humidity, though it may be done by enclosing

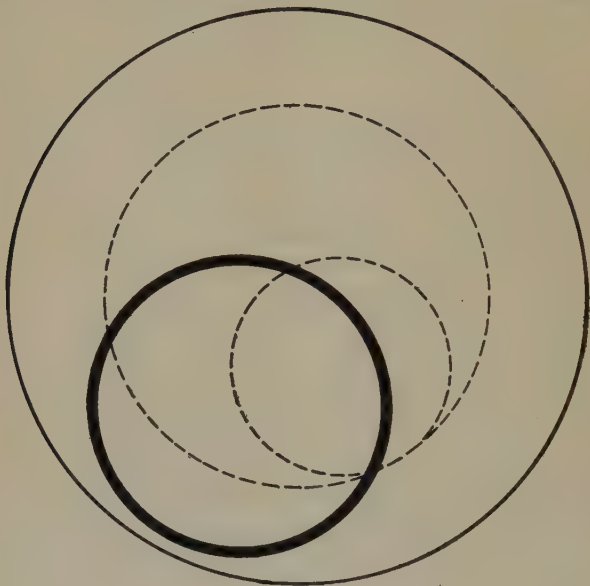


Fig. 187.

the work by a bell or cover and evaporating a small reservoir of water, according to the speed at which the machine works. It is fortunate for opticians, both employers and employed, that skill and experience are necessary, for which there can be no mechanical

substitute. It is true that much of the preliminary slitting, roughing and grinding can be executed by automatic or semi-automatic self-feeding tools, with

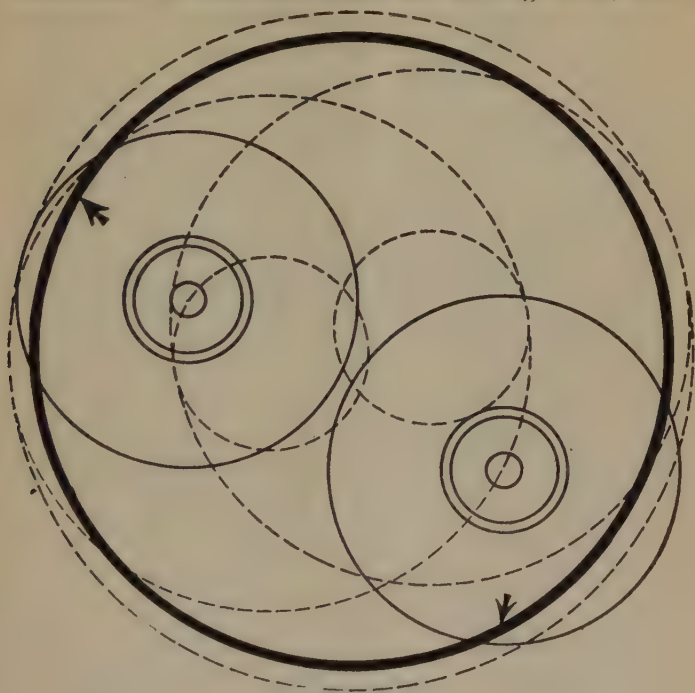


Fig. 188.

powdered carborundum and water as the abrasive. A good deal of very cheap work, such as lenses for toy cinematographs, magic lanterns, inexpensive reading-glasses, spectacles, eyeglasses, etc., is done by such

means, mostly abroad, and given but a minimum of polish; while many low-grade lenses are even formed by the simple expedient of pressing the glass while plastic into suitable moulds. Methods of this kind obviously are not worth serious consideration for any purpose that demands optical perfection. A mere glance is sufficient to show the comparative dullness of the surfaces, so different from the sparkling brightness of a first-rate lens. What is more important is that the entire action of any lens produced by a mechanical short-cut is bound to be markedly inferior.

The Stroke Alters the Surface. Other strokes for emerying for their special purpose are as Fig. 187. This stroke, if continually used, has a tendency to slightly hollow the surface, but the double round stroke (Fig. 188) worked with it will generally give good results. These will be amply sufficient to explain their use and action, but it must be left to practice to get perfect at this kind of work.

CHAPTER XXI

PRISM WORK; A BINOCULAR PRISM; METHOD OF WORKING

To make many of the prisms used is a very simple job, especially where the surfaces need not be got to a high state of perfection. but whatever work the prism has to do, it is best to give it as good a surface as possible. Take an ordinary equilateral prism for the first job to

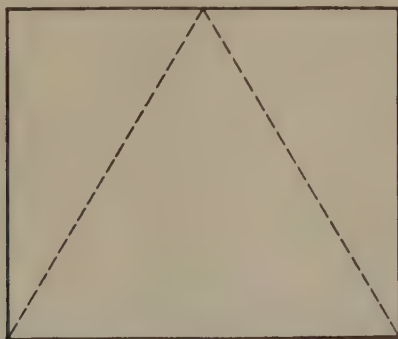


Fig. 189.

try your hand on. Get a piece of glass large enough to make the prism, and proceed to square it up on the roughing plate. This consists of an old flat tool or surface—in fact, anything that is thick and flat—and is seen in every shop for rubbing-down purposes.

True up one of the four faces on the finishing-tool, and from this face square the ends perfectly by means of rubbing down and trying them in every direction with a square; these ends should be ground pretty

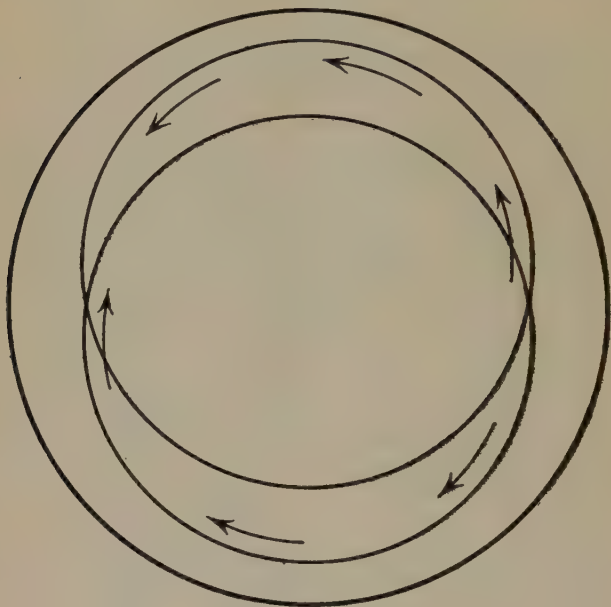


Fig. 190.

fine. Now with a lead pencil first, and a diamond point or the point of a sharp scraper, mark where the other two faces should be roughed down to, as in Fig 189, and proceed to rough them down on the roughing flat before mentioned. Take a good sweep round, and

do not put too much emery on at once, or you will find you are only grinding the emery into smaller grains, and hardly touching the glass. Another thing, keep changing the prism you are grinding from end to end, or you will have your surface turn wedge-shape; or if you are roughing it down with a circular sweep, keep

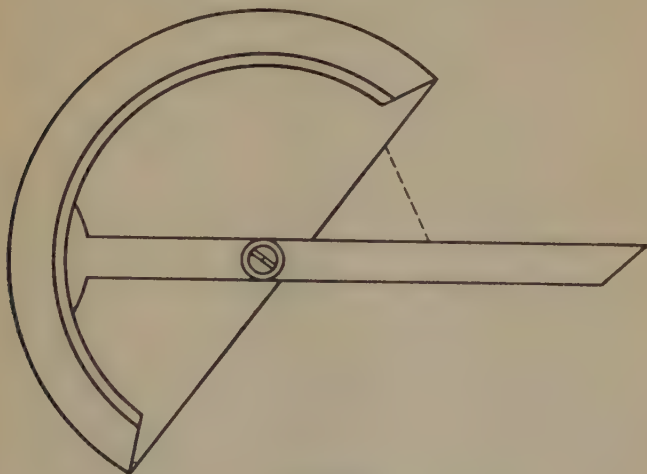


Fig. 191.

changing the direction : give five or six rubs from left to right, and five or six from right to left, as in Fig. 190. By this means you will keep your surface perfectly true. You should try your surfaces from time to time for the angle by means of the goniometer (Fig. 191). When right, the three sides can be emieried and then polished. They must be polished on paper used

dry, which is less liable to round the edges than cloth or silk. They can be polished by means of a strip of cartridge-paper put on to the true tool with starch and polished with rouge; or a paper polisher can be put on a small flat tool running on the lathe, and the polishing done by means of tripoli. A good deal of practice is required before you can be certain of a first-rate surface by either method. A small hole can be drilled

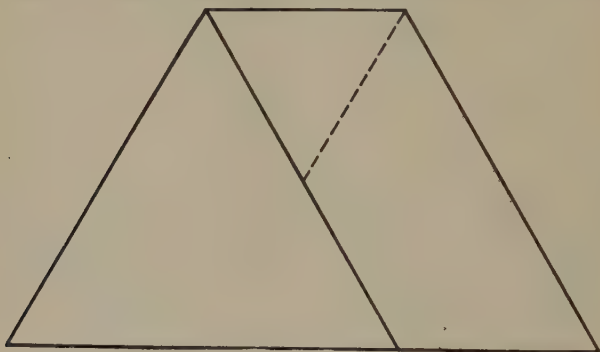


Fig. 192.

in the centre, if required, for it to swing between centres. To make an Amici prism, you must proceed as if you were making an equilateral prism with flat faces, and when ground up true, each face should be worked in a shallow concave tool, and polished on a strip of paper.

Prisms. The next which I shall describe will be the prisms of precision, the blocking up of which forms a very important part for getting the perfect surfaces required.

CHAPTER XXII

WORKING A BINOCULAR PRISM (*Continued*)

PRISMS that have a particular and special duty to perform must have all the faces perfectly true, and to get them to the pitch required the work must be done systematically, and one must not mind spending a certain amount of time in the preparation of rests that are, of course, useless afterwards, but necessary for the final perfect result. The faces must be practically perfect, or a distorted image is the result. One of the most difficult prisms to make is the binocular, so we will go through the different methods of getting them as near perfection as can be got. The tools we shall require will be a good flat and a runner, turned or planed as nearly parallel as possible. Get as many pieces of crown glass as will almost fill the runner, and proceed to square them up, and be very careful that the edges are square to one of the wide faces. When a sufficient number are ready, they can be stuck on to the flat runner by means of shellac thinned with Canada balsam. Put them systematically, as in Fig. 193, and grind down to the proper substance. You can try if you are keeping them parallel by means of calipers, trying all over the block, as in Fig. 194.

When to the proper substance, this block can be emiered and polished, using a good paper polisher well down on to the flat tool. Great care must be taken to

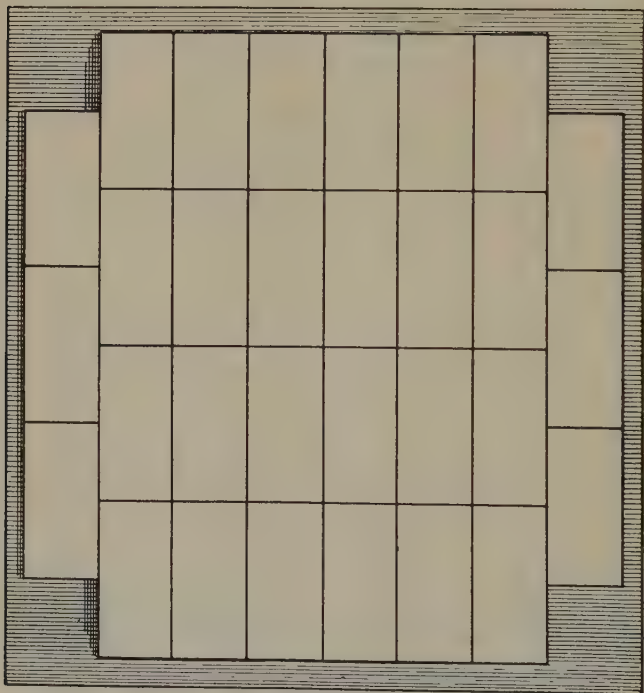


Fig. 193.

get the surface as perfect as possible, and if there is any doubt as to the surface, go back at once and emery again.

The First Surface of the Prism. When this surface

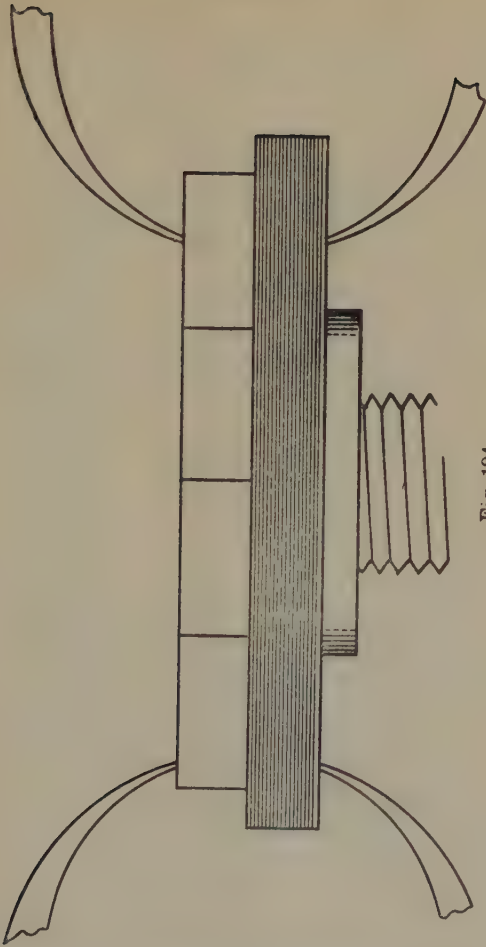


Fig. 194.

is perfect, the pieces of glass can be taken off. Of course

you have a good number worked, but it is always advisable to have a few extra. When off the runner the pieces of glass should be soaked off in methylated spirit, and put in a box, or anywhere where they are not likely to be damaged. Now clean the runner off, and cut up a few strips of French plate. These pieces of glass are to be ground to the angle necessary to lay the worked pieces of glass, so that when it is rubbed down parallel to the runner it will be to its proper angle. If a quantity of prisms are required, it would be best to have, instead of the breakable pieces of glass, pieces of brass planed to the proper angle, and fastened



Fig. 195.

to the runner by means of screws; but of course this means a lot of outlay, and as I am describing a makeshift way of getting the prism perfect, we shall go on as if the rest were of glass, and not brass. On the roughing plate get the pieces of glass down to the shape of Fig. 195, carefully testing them by means of the goniometer; then cement them at right angles to one of the sides of the runner. Now heat as many pieces of glass as will make a full block that are worked on one side, and cement them on to the rests, pressing them well down to be sure they are home. The block must also be pieced up at each end to prevent any possibility of rounding. The block should

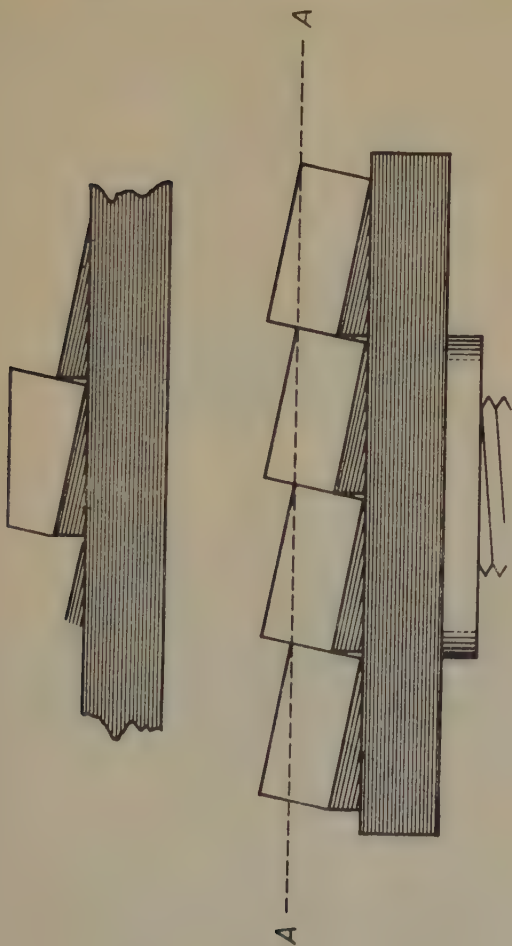


Fig. 196.

now appear as in Fig. 196, and when rubbed down to the dotted line *A* you will find that two sides are now to the proper angle. This side can also be worked and polished.

Working the Top Surface. The next side to be worked will be the top end ; this will require a rest of

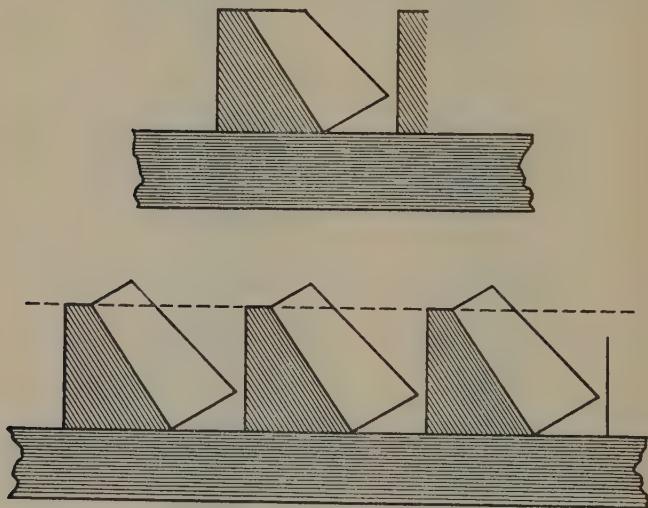


Fig. 197.

another angle, and a piece of glass should be so prepared. The same process of sticking on should be repeated, and the top face worked. You will see that the prism is now getting into shape (Fig. 197), and the base is the only surface left that requires to be worked. Of course, another rest of the necessary angle should be ground, and the last surface finished. By these

means a prism as perfect as possible can be made ; but it requires a good amount of patience to do the job perfectly. By having the rests that are ground first of slightly different angles, different deviations of the

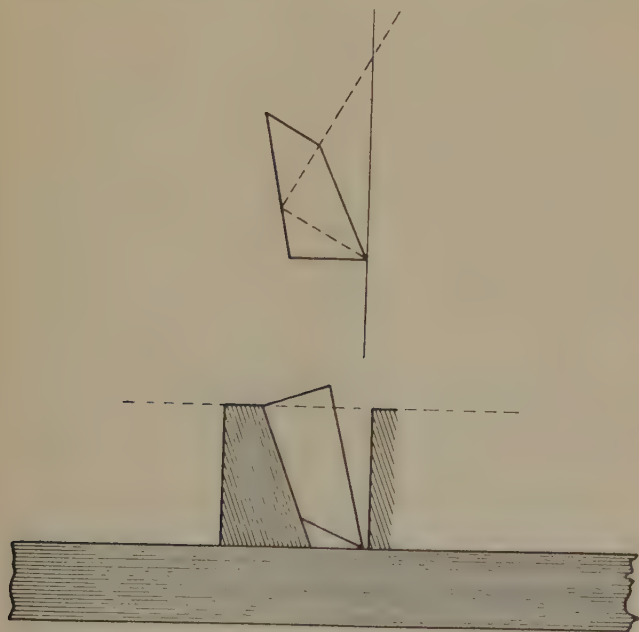


Fig. 198.

pencil of light can be effected, so that the binocular can be either narrow or wide, as wanted, though it is always the safest plan to make the binocular tubes to the prism. Fig. 198 will show the prism at the last working stage, and a section of it when finished.

CHAPTER XXIII

METHODS OF MOUNTING LENSES ; BURNISHERS ; MOUNTING
HEMISPHERICAL LENSES

LENSES that are ground and polished true, and also edged, may be spoilt by faulty mounting, or put into their cells greatly detrimental to their final performances. A badly centred system produces indistinctness of image, which naturally decreases towards the centre of the field of view. Nageli and Schwendener, on the microscope, say about testing the images in centring, "We have shown that imperfect centring of a system of lenses manifests itself generally in two ways: first, by producing indistinctness in the images, which first affects the margin of the field of view, and only in the case of greater deviations extends to the centres, in all cases, however, decreasing towards the centres; secondly, by the changes of position which any fixed image-point undergoes if the objective or one of its component lenses is rotated on the optic axis."

Systems must be truly Centred. The first point may be tested by determining the optical power of the microscope for different positions of the field of view and comparing results. It must be specially noticed whether the left margin gives decidedly more indis-

tinct images than the right, and whether there is inequality in the distribution of optical power and in its decrease from the centre towards the periphery. If these differences are not noticeable, or but slight loss towards the margins can be discovered, conditioned by the errors of the eyepiece and therefore proportional to them, we may be sure the errors of centring are corrected as far as possible.

Unscrewing the Cells to Test the Mounting. Regarding the second point, it is usually stated in micrographic works that the changes of position in question are revealed on revolution of the objective lenses by unscrewing the mounting. It is therefore only necessary to adjust the microscope on any small object, so that the image may touch the margin of the field of view, or a line of the eyepiece micrometer, imperfect centring then would be shown on unscrewing the lenses by a corresponding circular movement of the microscopic image. We mentioned this method of testing before, adding further details with regard to the factors upon which the amount of the displacement is dependent. We then stated that the movements of the image observed during the revolution of the objective lenses by unscrewing are dependent upon the accuracy of the construction of the mounting and the screw threads quite as much as upon the deviations of the optic axis before the unscrewing—a proposition the theoretical accuracy of which is unquestionable. Since then we have become convinced that the process amounts to nothing more than a testing of the mount-

ing. The errors of centring which occur in best lenses are so small in comparison with the eccentricity of screw threads that they play only a small part in the movements of the image. If, then, the lenses independent of the mountings are to be tested for centring, their unscrewing is detrimental to the purpose.

Testing the Cell. The only efficient method of testing the centring is that applied in practical optics. The metal cell of the back combination, which ought to be concentric with the universal screw on it, is attached to the lathe so that its own axis approximately coincides with the revolving axis. The accurate testing of this coincidence may be effected by means of the so-called "lever of contact," the shorter arm of which rests during the revolution upon the free surface of the cell, whilst the longer one projects freely backwards, and in case of inaccurate centring exhibits the movements of the short arm on an enlarged scale. When the cell is adjusted satisfactorily concentric, the lens is inserted and moved about until the errors of centring are eliminated as completely as possible. These errors are shown by the motion of the small reflected image of a window-frame or lamp-frame. The optician observes the image with a magnifying glass, and moves the lens till the image remains perfectly still during revolution.

The Image a Telltale. In testing a completed objective we screw the brass-work on the lathe, and commence with the back combination, and so on, add-

ing the others. If the images remain perfectly still during revolution, the centring is practically perfect. To make the lenses "go true" with certainty, they must fit the cell not too tight or too loose, but so that they drop easily to the shoulder. This should not be square, but tapered to let the convex surface rest easily, as in Fig. 199. The lenses must be nicely balsamed, not too hard, and a thin layer of black sealing-wax run down the inside of the cell, and after warming the lenses slightly, they should be pushed in, and set true

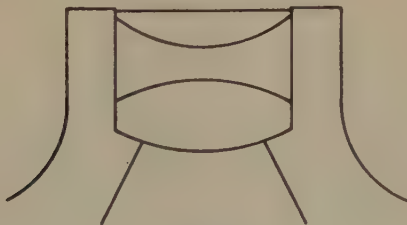


Fig. 199.

by means of a dogwood peg. In most foreign work the lenses are finally burnished in, that is a burr run over the face of the lens to keep it from moving. This is rather a delicate job, and great care must be exercised to prevent shattering the lenses or running the burr so tight as to make the contacts of the lenses stare. Fig. 200 will show a tool made from a piece of drawn steel that will be handy as a burnisher, though eyepieces and the common kind of work are generally run round by means of the ordinary arm-rest, as in Fig. 201. The edge of the cell should be turned very

thin. the lens kept in position by means of the finger riding on the centre; a slight turn of the arm-rest will throw a burr over the chamfer that is put on the glass



Fig. 200.



Fig. 203.



Fig. 202.

for that purpose; and the lens (if edged true) should go perfectly central. Figs. 202 and 203 are tools used also for throwing a burr over, the first being a tool that

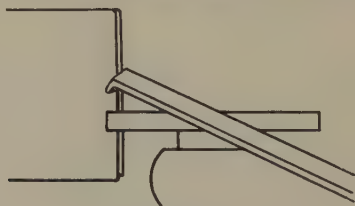


Fig. 201.

cuts a hollow near the edge of the lens, and the taper turns the burr over at the same time. This is very handy where lenses are put in with a broad flat, and

Fig. 204 will show the use of it. Fig. 203 is a small polisher roller, fitted like a milling tool, that answers the same purpose as the arm-rest, but is rather more

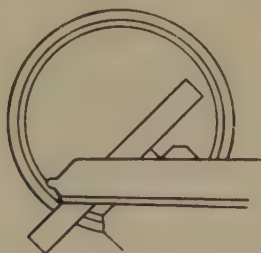


Fig. 204.

safe in use. Fig. 205 shows a method of mounting a hemispherical lens, so as to get the extreme angle. The lens is mounted from the back of its setting. Fig. 206 shows the mounting of a hemisphere on to a glass slip, which is first mounted from the front of the cell, and then the hemisphere is balsamed on to it from the back. True screw threads and square shoulders to them will be half the battle of mounting, and a nicely tapered shoulder will greatly facilitate the ultimate



Fig. 205.



Fig. 206.

object in view. It is always as well to give the cells a coating of black by means of chemical bronze before putting the lenses in, though most of the foreign firms mount their work bright.

CHAPTER XXIV

TESTING DIFFERENT LENS SYSTEMS

As we have been through the most general work appertaining to practical optical work, we shall conclude with a description of how to test by easy methods the workmanship, as well as the computations, of different systems. The first to describe is an eyepiece, as we shall have to use this piece of apparatus for the determination of the other optical parts of the instrument. We have our lenses for the eyepiece one about three times the focus of the other, and we place them at a distance of twice the focal length of deepest lens; thus, if the field-lens, or the lens placed nearest to the objective, is of 3in. focus, the eye-lens, or the lens nearest to the eye, should be of 1in. focus. Now double the distance of the eye-lens, and you have the proper distance of the combination—that is, 2in. Now you can put a stop between, that will give you as large a field as possible, opening it so that it just cuts off the blur at the edge or bevel of the field-glass; you then know that you have as much out of your eyepiece as you can expect. When you have pushed the stop sharp in focus of the eye, there should appear on the edge of the stop a circle of blue colour. You must be very par-

ticular to get the field-lens perfectly clear and free from marks, or they will show with the eye-lens; also the lenses must be systematically worked fine, and not blinded over and scrubbed up, or on looking through your instrument you will find the field a spotty, patchy mass, as if you were looking through imperfectly ground glass, and the motley appearance will be more intense when the instrument is racked out of focus.

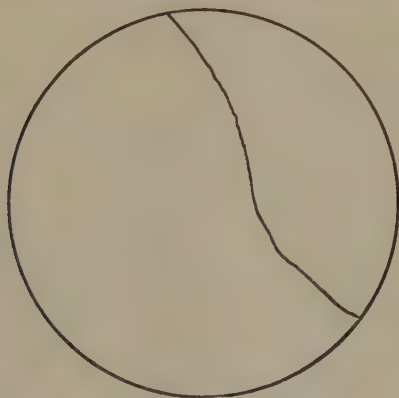


Fig. 207.

Also any veins and striæ in the glass will show like cords or rope stretched across the field (Fig. 207), and will, of course, be very detrimental to the image. The lenses should be edged perfectly true and bezelled in.

Testing Eyepiece Lenses. Many of the cheap French eyepieces are wedge-shaped, as for cheapness they are edged before they are worked; thus the out-sides of the block get more working than the centres,

as explained, which leaves the glass a wedge, and practically a prism also. Many of the lenses which happen to be at the outside of the block have a ripply surface. It must be obvious to the reader that if the eyepiece is faulty the image of the object in view must be proportionately so. I have seen many good instruments utterly spoilt by the wretched eyepieces put to them, which is done for cheapness, and the stand-maker will often give an objective an exhaustive testing, and condemn a system for a slight fault that would not have any effect on its performance, but will fit an instrument with eyepieces absolutely worthless. The eyepiece is intended to refract pencils of rays which come from the objective to form the real image, that they may all arrive at the pupil of the observer's eye, and it has to form the virtual image which is presented to it as the object. We now have our eyepiece as perfect as possible under the given conditions.

Testing an Objective. From the eyepiece we now turn to the objective, and proceed to test this. We have a shallow-power system—say a 2in.—composed of two pairs of lenses. The first thing we will do is to try the lens on an object that perhaps is well known to us to see how it looks, and the image is not so good as we have reason to expect; so we proceed to use various tests to find out where the objective fails to satisfy its requirements. In shallow-power systems it is generally the rule to have both combinations approximately achromatic, and each ought to show on examination any fault that it has. For the first test let us take a

globule of mercury. This must be knocked into several small balls on to a blackened plate. Unscrew the front lens, take it away, and focus the back pair on to the mercury globule. This is best done by daylight, as the colours are more distinct; in fact, some colours are totally unobservable by artificial light. Now take notice of the colour that appears on the globule itself, and then rack the instrument down and observe what colour it turns to, and then rack up and observe that also. We shall suppose our lens to be passably corrected, and the colour on the globule should be a greenish red. When the instrument is racked down, the green only should appear, and when racked up the red only. If the mercury globule is free from colour and looks black, all the better, for then you can be sure of your objective standing the highest eyepieces.

Testing with Mercury Globules. We have only one globule in the field, and hitherto we have been examining it in the centre of it. Now move it to the extreme edge of the field, and examine as before. If the pair is not perfectly corrected, they will show a mixture of colours, and that will show that the pair is only corrected for the central rays; all the others, being imperfectly blended, only show a foggy and indistinct image. Let us suppose that our pair stood this test, and we will knock a few more globules on the dark slide, so that we shall have ten or a dozen in the field of view at once. There is, perhaps, not much difference in the size; if there is, smash the largest ones up. Now get one in the centre of the field, and focus it sharp; if you

are examining by light from a window, focus the sashes of the window as sharp as you can (Fig. 208). Now



Fig. 208.

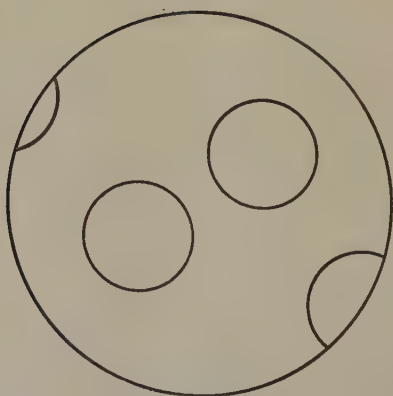


Fig. 209.

look at the globules of mercury at the edge of the field, and see if they are also in focus (Fig. 209) ; if not, your lens will never be very flat if your front combination

is corrected the same way ; if not, there is still hope for the lens being made decent.

Testing the Workmanship of the Surfaces. If the globules of mercury are pretty well in focus all over the field, we will next try the workmanship of the surfaces that compose the pair. First get a globule of mercury that is fairly large (according to the power of

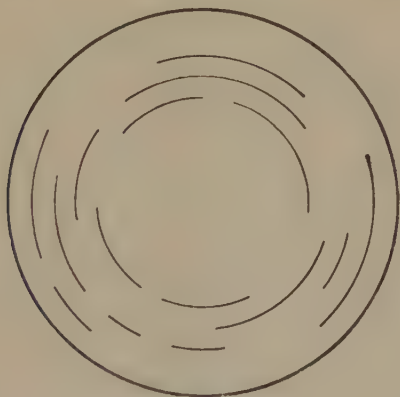


Fig. 210.

the lens), and get it as nearly central in the field as you can. Now focus the pair up from it, and notice the enlarged ring that forms above it. This should continue perfectly round until lost at the edge of the field (Fig. 210); but it sometimes happens that, directly the ring has formed above the mercury, it has a protuberance (Fig. 211) from one part of it. More often the ring forms itself in the shape of a pear. Sometimes the ring

is mutilated with two, and even three, of these "lumps," and directly they are seen it is best to take the lenses from their settings and examine the surfaces, and so save time. But we will suppose the pair passes muster, and has a perfect ring. Now all these conditions are satisfied, and we shall examine the mercury again. When we look at it we see that though the

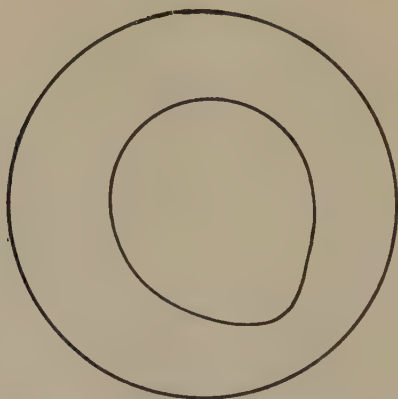


Fig. 211.

colour is good, the field pretty flat, and the surfaces well worked, on top of the globule of mercury, or at least at the side from the point of light (the window or gas-jet), a tail of light appears (Fig. 212), just like the tail of a comet. This is termed "coma," or "fringe," in a microscope objective, and "flare" in a photographic system. If we move our eye round the eyepiece, we notice that this flare follows us round; and if we put

the pair on to an object and try it, though it seems to have satisfied the requirements (with the exception of the coma) by the mercury test, the object, though passable by a shallow eyepiece, shows with a deep one an indistinct image which is covered by a fog that spoils all performance. With the exception of this slight star, or coma, the lens would seem to pass by

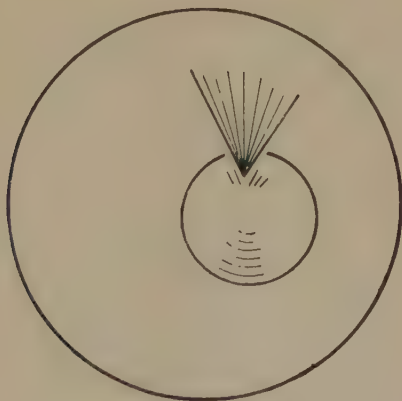


Fig. 212.

the mercury test; but we have as yet only examined it by reflected light, and directly it is examined by transmitted light the faults show up.

The Black and White Test. Ordinary objects are not a good test to find faults with, though they are fast enough at showing them, so we must get or make an artificial object that will suit our purpose. We will get a 3×1 slip and hold it over a smoky lamp until

the surface has a fine film of black over. Now, with a fine needle, draw a few straight lines and touch the surface here and there with the point of the needle, and we have one of the best test plates that can be used. The transparent and the opaque parts lie on the same plane, and it is an excellent test for flatness of field.

CHAPTER XXV

GENERAL TESTING OF SYSTEMS OF PRECISION

THIS object can be protected in several ways by flowing a little turps over it to fix the black, and then a thin cover of glass balsamed over it. If we look at one of the straight lines on the test-plate through a

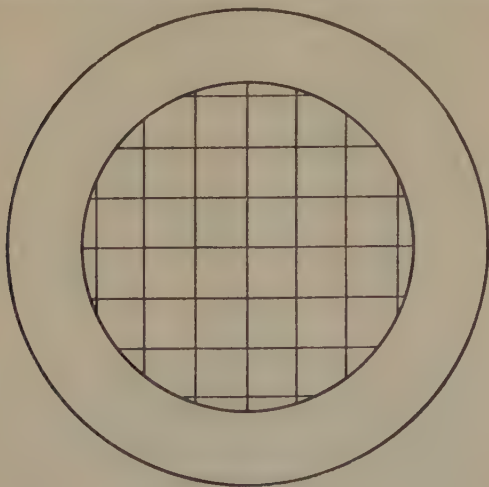


Fig. 218.

lens, its image only appears to be straight when it runs directly through the centre of the field ; if you

put it at a little distance from the centre, it appears curved with its convex side towards the centre and the curvature varies according to the distance from the centre. If a ruled meshwork of squares, like Fig. 213, be focussed, it will appear in an imperfect lens like Fig. 214, and any other object will appear more or less

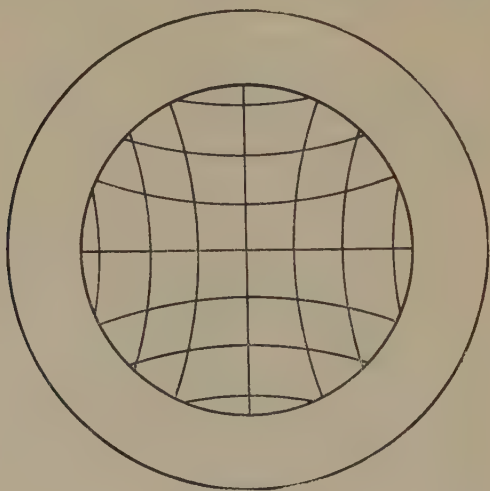


Fig. 214.

distorted, sometimes with the opposite effect, like Fig. 215. We can test these images which are formed by the objectives thus:—Take the eye-lens away from the eyepiece, and put a cover-glass with a straight edge on the stop of the eyepiece, so that the edge appears in the circle as a line (*m n* of Fig. 216). A real image of one of the lines on the plate is made to

coincide with the chord, precisely as the adjustment of a particular division-line to the margin of an object is effected in micrometer measurements. If a complete coincidence takes place, then the real image is free from distortion. A distortion, as in Fig. 215, where the marginal parts appear less enlarged than

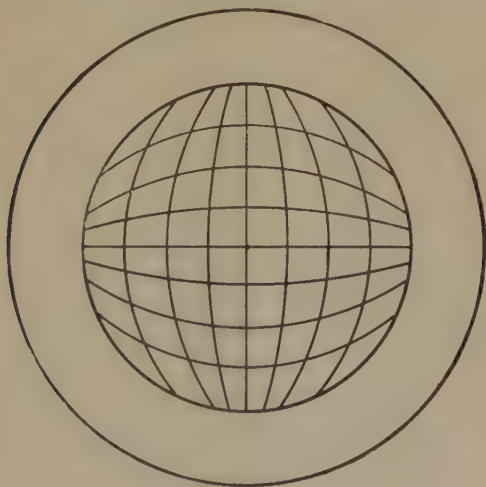


Fig. 215.

those in the centre, may be distinguished thus: when the two lines are in contact in the centre, the ends of the straight line *m n*, which is in the eyepiece, are bent outwards, whilst the opposite distortion is indicated by the deviation of these ends inwards (Figs. 217, 218). From the curvature of the straight line *m n*, the curvature of the virtual image, which the eye-

lens forms of a flat surface under given circumstances, may be seen.

Testing the Field of an Objective. In order to test the curvature of the image surface, we can examine the marks of the test-plate, and observe whether all the points of the field of view can be clearly seen at

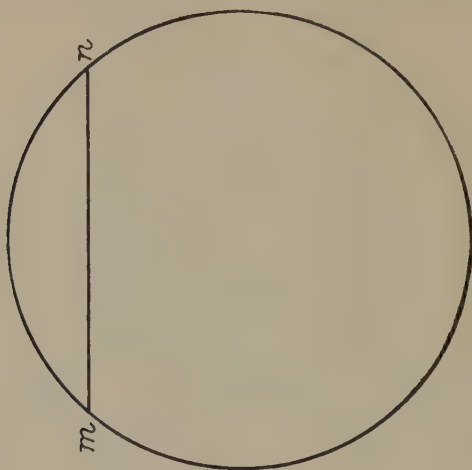


Fig. 216.

the same time. If we find, as we generally do, that the edge requires a lower focal adjustment than the centre, then the image surface is evidently convex to the upper side. The curvature is, of course, greater in proportion to the differences of plane. To test the spherical aberration, which is one of the most influential factors of a lens, its determination, and the

discovery of the precise action of the lens combination, together form one of the most important problems. In the first place, the question arises in practice how the presence of spherical aberration shows itself on the image formed by the lens; and, in the second place, we have to decide whether it indicates an under-

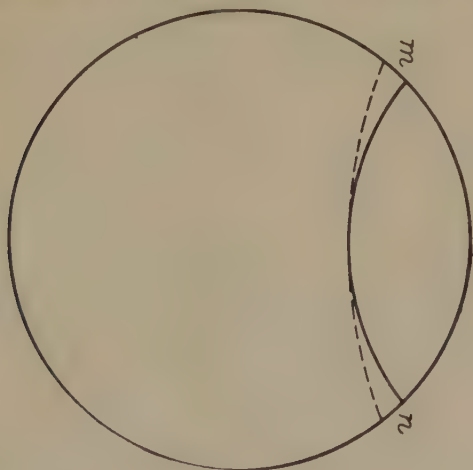


Fig. 217.

correction or an overcorrection. Sometimes an objective will be undercorrected for the central rays, and overcorrected for the marginal ones; but a lens is judged by its total effect; if the central rays largely predominate, or the marginal rays are in the majority, as more often occurs, the lens system shows no marked aberration. The general action of spherical aberration may be shown graphically.

If $a b$, Fig. 219, is a self-luminous object whose cone of rays completely fills the aperture of the objective $A B$, and if we assume that the rays emerging from a and b unite after refraction for the most part in the points a' and b' , while the others converge towards points lying somewhat nearer or further, and which

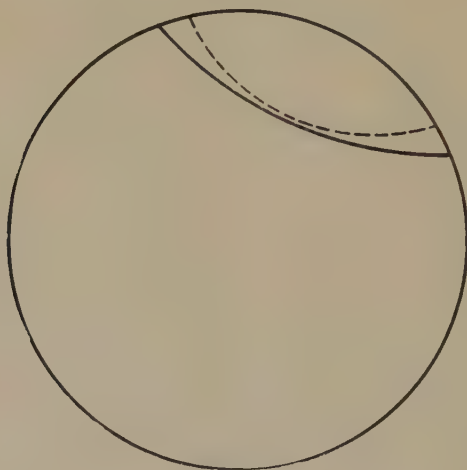


Fig. 218.

are more or less separated, as shown in the figure, for the central and marginal pair of rays, the real image of the point a appears in a' , and that of b in b' ; consequently the images of the other points of the object appear in the intermediate points between a' and b' . An image plane drawn through the points a' and b' would, as the construction shows, be met beyond

these points by the other rays, whose focal points fall in front or behind this plane. These rays do not originate merely from the extreme marginal points of the object a and b , but also from the adjacent ones up to a certain distance from the margin, from which point also the aberrant rays cut the surface of projection of the image. The observer, therefore, looking through the eyepiece at the image formed by the objective, perceives outside the margins a' and b' of the

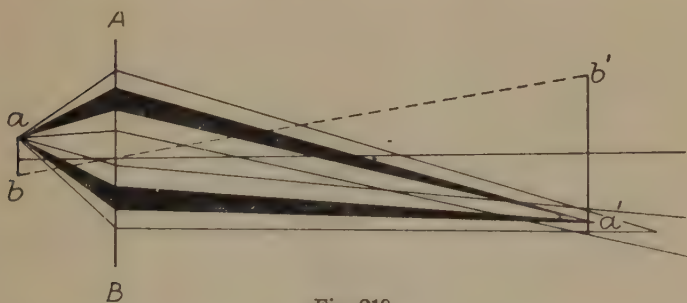


Fig. 219.

illuminated surface image a fog, due to the rays affected with aberration. The testing of the aberration can therefore be simply effected by viewing a small luminous surface, or a real or virtual image which acts as such a surface. The fainter, therefore, the fog surrounding the image, the more perfect is the correction of the aberration.

Correction. In practice the condition must be fulfilled which every test object ought to satisfy: that the cones of rays proceeding from the illuminating

points should occupy the whole aperture of the objectives. For this purpose the diaphragm must be removed or sufficiently enlarged for the lower powers, and the mirror brought near; but with the higher powers a condenser should be placed beneath the stage, and if the objective has an aperture of 60° , the illuminating cone of rays falling on the slide should have an aperture at least as large. The question whether an

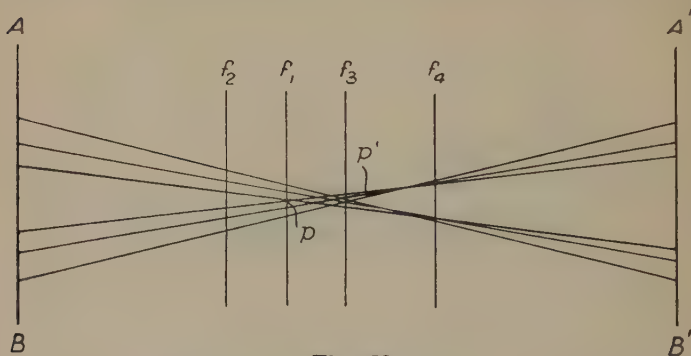


Fig. 220.

object is undercorrected or overcorrected is based upon the phenomena which are produced by the varying distance of the eyepiece, or what in principle is equivalent: the increase or decrease of the object distance. If we take the simple case of the aberrations all following the same way, so that the refraction of the objective gradually increases or decreases from the centre of the periphery, the effect of change in the focal adjustments can be readily understood. If $A B$. Fig.

220, is the objective, p the focal point, or the small focal space occupied by all the central rays, up to a certain inclination, and $p p'$ the greatest length of the aberrations of the marginal rays, for which, therefore, the objective is overcorrected, the real image will be most clearly seen when it coincides with the plane f_1 drawn through the point p . This image appears, however, bordered by fog, caused by the marginal rays incident on the surrounding parts. If the screen is moved further to the left in the position f_2 , it cuts both the central cone and the aberrant peripheral rays in the larger surfaces; the image must be dim while the fog increases in extent. If, on the other hand, the displacement takes place in the opposite direction, the cross section of the solid cone of rays becomes at first smaller, attaining its minimum at f_3 , where the peripheral rays intersect with the image-forming rays, and consequently the fog disappears. The screen is therefore illuminated in f_3 by a sharply bounded circle of light. Further to the right the latter again increases in extent; it retains, however, the same sharp outline because the peripheral rays are projected within it. In the neighbourhood of f_4 even the marginal zone of the circle of light appears decidedly brighter, because here the aberrant rays approach the upper surface of the central cone; it contrasts, therefore, still more decidedly than before with the dark surroundings.

Spherical Aberration. The phenomena are precisely reversed when the spherical aberration is undercor-

rected for the peripheral rays. In order to apply the same construction in this case, let us suppose in the above figure the objective is $A' B'$, instead of $A B$. The path of the rays corresponds to the opposite aberration, and the same movement of the screen, which as regards $A B$ was an approximation, is now receding with regard to A' and B' . The projections of the united cones of rays remain the same in the different positions. If, therefore, the microscope is focussed on the illuminating surface as accurately as possible, the approximation of the eyepiece is accompanied in an overcorrected system with a stronger appearance of fog, in an undercorrected one by the formation of a sharply defined disc of light somewhat clearer at the edge; whilst increasing the distance of the eyepiece always produces the opposite appearance. The same effect is also obtained within the limits here considered, if for the displacements of the eyepiece are substituted corresponding displacements of the object: instead of moving the eyepiece nearer or further with respect to the objectives, the object is brought nearer or further, or the body-tube is lowered or raised. When, therefore, an approximation produces more fog, or increasing the distance produces a well-defined circle of light, there is overcorrection, and where the converse phenomena appear undercorrection.

Under and Overcorrection. With these effects of spherical aberration, which are clearly apparent to the eye, are associated those of chromatic aberration, which, as a rule, further increase the contrasts. In

consequence of this the fog appears bluish, and the disc of light has a greenish-yellow border, red at the extreme edge, which appears up to a certain limit, the more decided the greater its diameter. The distinction between undercorrected and overcorrected aberration is thus still further facilitated. It is added, as a further criterion of the two opposite aberrations, the fact that the fine details of the image (for instance, the window-frame where mercury globules are used) disappear at once on the approximation of the object, but only slowly on its withdrawal if the objective is undercorrected, and conversely in an overcorrected instrument.

Thus generally stated, this assertion is inaccurate, having submitted the matter to test. In one special case, in Fig. 220, precisely the converse took place, for it is clear that a displacement of the screen in the direction of f_1 towards f_4 influences the distinctness of the image less than the opposite displacement, as all the focal points of the peripheral rays, and consequently the images corresponding to them, lie to the right of f_1 between p and p' . A displacement in the direction corresponds in an undercorrected objective to an approximation, and in an overcorrected one to a withdrawal of the object.

Practical Processes of Testing. The practical processes of testing are consequently confined to the following points:—(1) We give to the cone of light proceeding from the mirror an angle as large as that of the objective to be examined. With high-power objectives this is accomplished by the application of a

suitable illuminating apparatus, or by placing an objective lens from $\frac{1}{2}$ in. to $\frac{3}{4}$ in. in diameter under the stage. (2) We focus the microscope to that plane in which the details of the image (for instance, the edges of fine fissures in the blackened plate) are most distinctly seen. If then a bluish fog is noticeable in the part surrounding the image, the aberration is not sufficiently corrected. (3) In order to decide which rays of the incident cone are affected by aberration, the illuminating apparatus or the diaphragm must be gradually withdrawn. If the bluish fog rapidly decreases or entirely disappears, the aberration is confined to the marginal rays; if it retains the same intensity for some time, the cause of the phenomenon lies in the central rays. In the latter case, which on the whole occurs less often, the fog should disappear if the central part of the objective is covered by a suitable stop. (4) We test the phenomena which a higher or lower focal adjustment causes. In doubtful cases an alteration of the position of the eyepiece is to be preferred. The overcorrection of the objective with regard to the marginal rays is hence recognised by the fact that the bluish fog with lower adjustment extends further, but with higher adjustment immediately disappears, so that the microscopic image appears as a sharply bounded circle of light with greenish-yellow border. Undercorrection is characterised by the same contrasts in an opposite sequence. (5) The aberration of the central rays can only be more accurately ascertained if the effect of light

thereby occasioned is apparent—a case which, according to experience, hardly ever occurs. (6) If the phenomena mentioned in (4) are undecided—the bluish fog, for instance, remaining perceptible for a short time, both with higher and lower adjustments—then both kinds of aberration are present in the peripheral parts of the cone, in consequence of an inaccurate curvature of the refracting surfaces.

Make a Prism of the Lens to Test the Chromatic Aberration. The simplest and most reliable method of testing the chromatic aberration of a system of lenses is to cover one-half of the anterior or posterior surface with a dark stop, so that only one-half of the system remains effective. If we then view a line of light, or a small luminous surface—for instance, a needle-mark on the blackened plate—it will appear colourless in an instrument that is perfectly achromatic; but in an under or overcorrected one it will be encircled on one side by a blue border, and on the other by an orange-red or yellow one. What arrangement these colours will exhibit depending on the kind of aberration present may be found by reference to Fig. 221. Let AB be the objective to be tested, the right half being covered by the diaphragm P . Since the uncovered half acts as a prism, then if the chromatic aberration is undercorrected, the differently coloured real images of the object ab must be so displaced that the violet one ($a'_v b'_v$) projects the farthest on the right, and the red ($a'_r b'_r$) on the left. The image has, therefore, on the right side a blue or violet border, and on the left

a red or orange-coloured one. If, on the other hand, the chromatic aberration is overcorrected, the left side appears violet, and the right orange or red.



Fig. 221.

Testing with a Self-luminous Object. Let W , Fig. 222, be the self-luminous surface under observation—for instance, the virtual image of a mercury globule.

The medium focal adjustment gives a sharp and generally colourless image, because the incident cones of light occupy the whole aperture of the objective

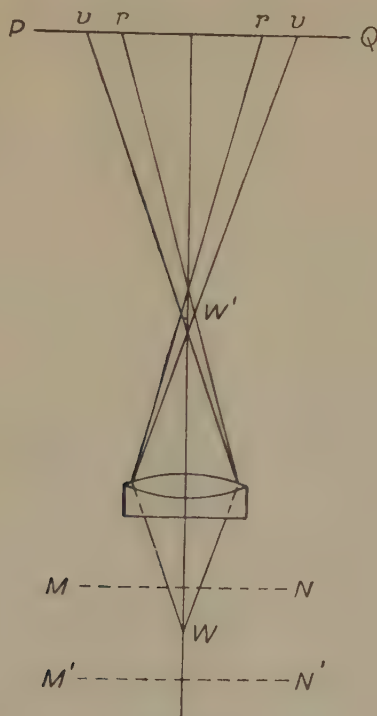


Fig. 222.

and the opposite aberration colours of the right and left half unite to form white light. If we raise the focus of the microscope to the plane *M N*, the con-

ditions of the refraction of the rays are essentially altered. The real image now appears lower down in the body-tube at W' , and the eyepiece receives only the diverging rays which are projected as a circle of light on the image plane PQ . Each half of the eyepiece acts separately. A given sector of the circle of light is formed by a corresponding but opposite sector of the objective, and consequently shows also traces of the aberration peculiar to the latter. If the objective is undercorrected—that is, if the violet rays (v) are more strongly refracted than the red (r)—the circle of light has a blue border, and in the case of overcorrection a red one, as shown by the construction. A precisely analogous proof may be given that, if the microscope is focussed to the lower plane $M'N'$, the opposite colours will appear, a red border indicating undercorrection, and a blue one overcorrection. This method of testing is very simple, and it is theoretically accurate.

Testing by a Minute Aperture. The former method appears to give more definite results where minute traces of aberration are under consideration. To avoid the somewhat delicate operation of covering up portions of the lenses, a minute aperture in the test-slide may be adjusted in the centre of the field of view. The mirror is then moved laterally out of the axis of the microscope (Fig. 223); the incident cone will then meet only that half of the objective which is opposed to the mirror. The foregoing are the methods of testing used for the best microscope objectives; but any

system can be examined, as all lenses follow the same rule. The differences of the fittings required for their examination are, of course, in proportion to their size.

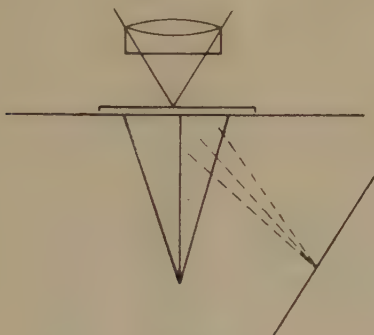


Fig. 223.

Testing Photographic Lenses. Camera lenses are tested on the "horse," the eyepiece is fixed as in a microscope, but horizontal, and the carrier made to slide backwards and forwards 10ft. or so, and the test-



Fig. 224.

ball or flame, or whatever is used, a fixture at the extreme end, as shown in Fig. 224.

CHAPTER XXVI

TESTING THE APERTURE OF LENSES AND DESCRIPTION
OF THE INSTRUMENTS AND METHOD

SINCE the power of discrimination of microscopes increases and diminishes with the aperture of the objective, the aperture belongs to the factors which must be taken into consideration in the testing of instruments. Its determination may be made in many different ways, yet all methods which have been proposed by different authorities are practically the same. They cannot possibly have any other basis than the easily understood phenomena which have reference to the known path of rays in an optical system. One diagram, therefore, will suffice to verify and elucidate the most different methods of testing. Let A , B , and C (Fig. 225) be three pairs of principal planes of the objective field-lens and eye-lens respectively, and F and F' be the focal planes belonging to A , and p the centre of the field of view. If, then, $m p n$ is the angle of aperture of the objective, an illuminating cone of equal aperture is of course necessary to fill it entirely. It is also evident that any small portion of the cone will illuminate the surface element p according to the degree of its intensity. If, therefore, a source

of light of slight extent (whether it be a diaphragm illuminated by the mirror, or the illuminating apparatus itself, or the distant flame of a lamp, etc.) is moved in the direction from a to b , or conversely from b to a , the object p appears to be illuminated as long as the source of light is situated wholly or partially within the space limited by the angle $apb = mpn$. Outside this angular space, the rays directed towards p do not reach the objective, or are so refracted that they do not reach the eyepiece; the field of view consequently appears dark. (In the figure this case is indicated by the dotted line xm .) The like result would obtain if a circular diaphragm, D , entirely within the illuminating cone, were

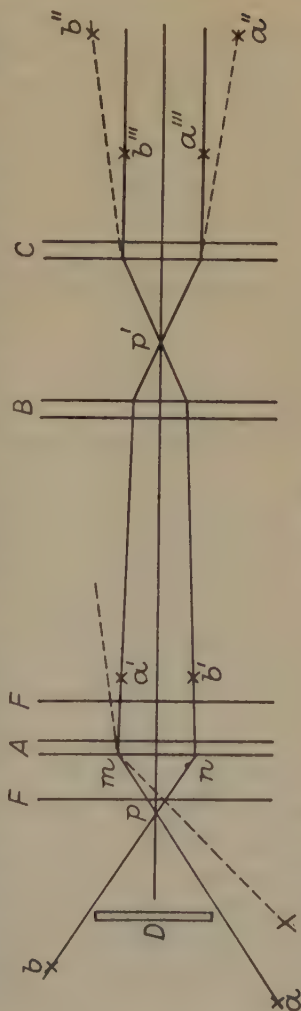


Fig. 225.

brought near to the object p until its edges touched the bounding surface of the cone.

Angle of Aperture. The real image is formed between the field-lens and the eye-lens. From this point the rays again diverge, and are refracted by the eye-lens, so that they appear to come from a point in the optic axis which is at the distance of distinct vision from the eye. If the eye is adjusted to infinite distance, the rays are parallel to each other and to the axis. Conversely, if a pencil of parallel rays is incident on the eyepiece in the direction of the axis, the rays first intersect in p' and then in p , and thence diverge in a solid cone between $p a$ and $p b$. A screen placed on the left of p at right angles to the axis is therefore illuminated to an extent which is dependent upon the distance from p and the angle of aperture of the objective. If the screen has the form of a circular arc described about p , and is divided into degrees, the angle of aperture may be read off. If the source of light a , placed at some distance, is regarded as the object, its objective image will appear somewhat behind F' in a . Of this image the field-lens would form a second one at a'' , but the eye-lens takes up the rays before their union, so that the actual image is now formed at a''' . If the light is moved from a to b , the image passes from a''' to b''' ; it disappears, however, as soon as the limiting line $b p$ or the opposite one $a p$ is exceeded. The diminution of the image may readily be calculated for given distances and focal lengths. If, for instance, the distance of the

light from the objective equals 1 metre, and the focal lengths of the objective, field-lens, and eye-lens are respectively 5.50 and 25mm., and the length of the eyepiece setting 50mm., we get with an ordinary tube length of about 200mm. a diminution of about 800.

Different Methods of Measuring the Aperture. On the basis of these theoretical deductions, sundry practical methods of measuring apertures have been devised which I will explain. In Lister's method the microscope is placed horizontally, and a lamp is adjusted at some distance from the objective in a darkened room. The lamp is then moved to the right or left of the axis until only half the field of view appears illuminated. The angle at which the extreme positions of the lamp (*a* and *b*, Fig. 225) are seen from the focal point of the objective is the angle of aperture sought. It is, therefore, only necessary to place the microscope in a suitable position or on lines to the extreme points right and left occupied by the lamp, and measure the included angle with the protractor. The method is still simpler if the lamp (a few feet distant) remains fixed and the microscope is revolved round a vertical axis (or, as is used in shops, a special instrument, as in Figs. 226 and 227, to lay the body-tube of a microscope on) passing through the focal point, so that the end of the eyepiece describes a horizontal arc. The result will be precisely as in the previous case. The microscope is first turned to one side and then to the other, in each case until half the

field is dark. In these extreme positions lines parallel to the axis are drawn and produced till they meet at the focal point. The angle which they include is equal to the angle of aperture, and may be measured directly by the protractor. The result is practically the same if the revolution does not take place exactly on the focal point, but merely on the anterior end of the microscope.

The Angle Board. If a special mechanical contrivance (as Figs. 226 and 227) be desired for such measurements, this apparatus is good, which consists essentially of a circular brass plate, upon which the body of a microscope is placed, and which rotates upon a fixed plate that is graduated on the circumference; a pointer on the rotating plate enables the observer to read off the angle on the graduated plate. In Amici's method the microscope is placed horizontally, and directed towards a distant source of light—*e.g.*, the flame of a lamp. Instead, however, of observing the field of view in the usual way, the image of the flame is examined with a magnifying lens above the eyepiece (a''' and b''' , Fig. 225). The microscope is then rotated in a horizontal plane to the right and left till a certain point of the image—for instance, its centre—just disappears. The arc which the microscope thus describes may be regarded as corresponding to the angle of aperture of the objective. This method has the great advantage that it not only has the aperture (that is, as far as it admits light), but also the extent of the really effective part, *i.e.*, the part which

produces images free from aberration. It is indeed

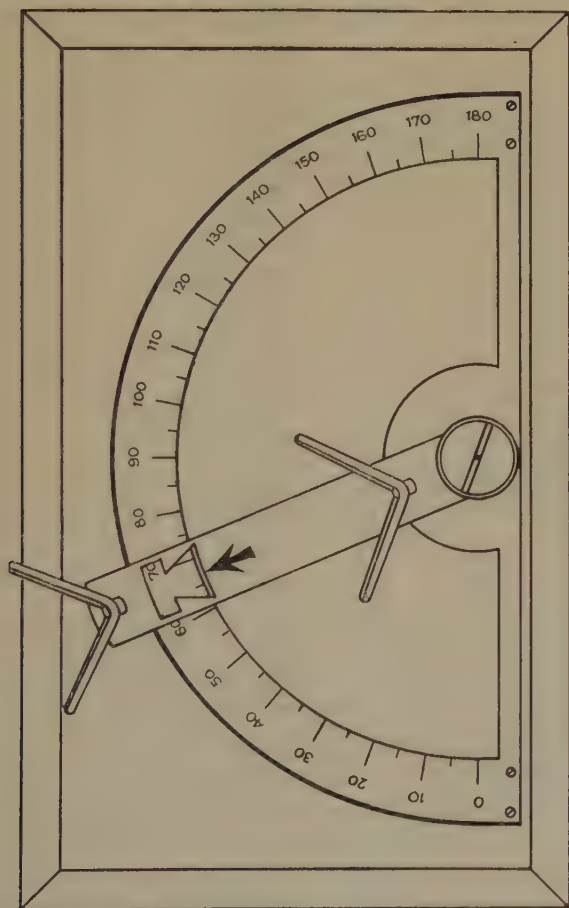


Fig. 226.

frequently observed that the images are indistinct and

distorted before they disappear, while they seem other-

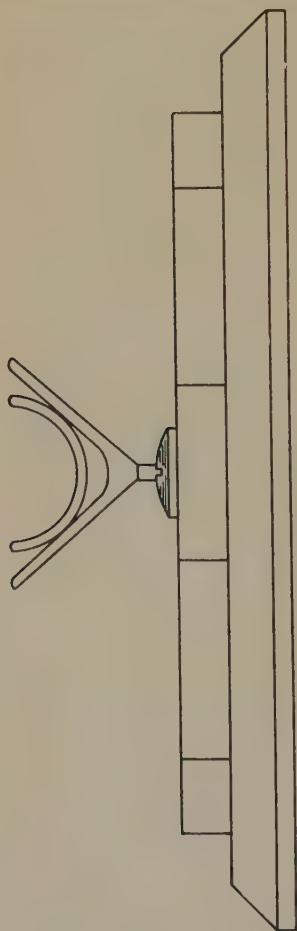


Fig. 227.

wise sharply outlined in their true shape. These indistinct and distorted images are of course produced by the marginal rays, for which the objective is no longer sufficiently corrected, and which are, therefore, better stopped off. The really effective part of the angle of aperture is consequently determined by the limits within which the flame appears sharp and clear.

Dr. Robinson's Method.

Another method, by Dr. Robinson, is this: A pencil of rays is projected in the direction of the axis through the eyepiece, and after the crossing of the rays in the focal point of the microscope is received on a screen. In Abbe's method a horizontal scale is applied under the object stage at a known distance from the plane of adjust-

ment, whose zero point is approximately in the centre of the field of view. Pointers are moved along the scale to the right and left until they touch the margin of the bright circular aperture image in the upper focal plane of the objective. The positions of the pointers are now read off, and the arithmetical mean taken, by which the possibly somewhat excentric position of the zero point is corrected. We thus obtain the linear distance of the extreme marginal points shown in the

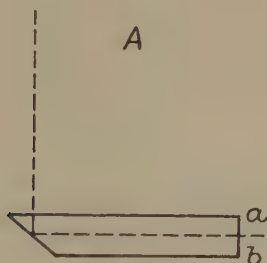


Fig. 228.

focal plane of the objective, and since this distance is proportional to the sines of the angle of aperture, the latter can at once be determined by reference to a table in which the angular values corresponding to the different distances are once for all computed.

The Abbe Apertometer. In order to obtain a greater illumination for greater distances, Abbe's scale is applied to the side ab (Fig. 228), and to the two adjacent sides am and bn (Fig. 229), of a rectangular plate of glass, though in recent times it has been made

semicircular in shape (as in Fig. 230), and is viewed from above by the reflection at the surface $m n$, which

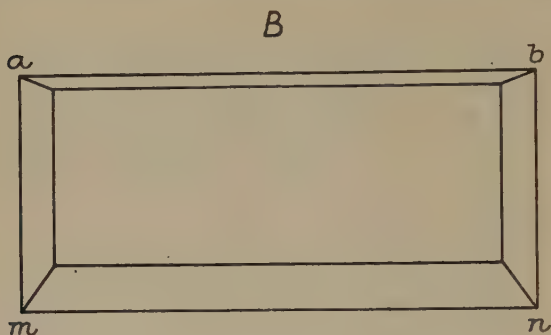


Fig. 229.

is inclined at an angle of 45° . By continuing the graduations of the scale upon the two sides at right

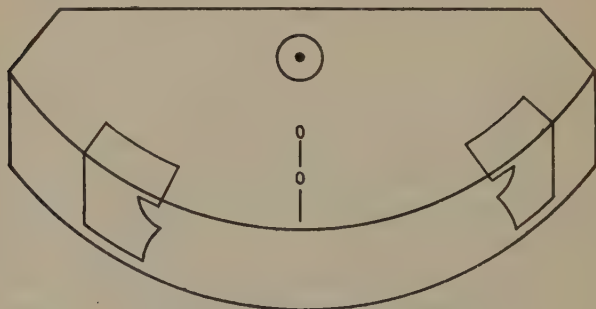


Fig. 230.

angles to $a b$, the size of the plate is rendered more convenient, and the illumination is stronger. For

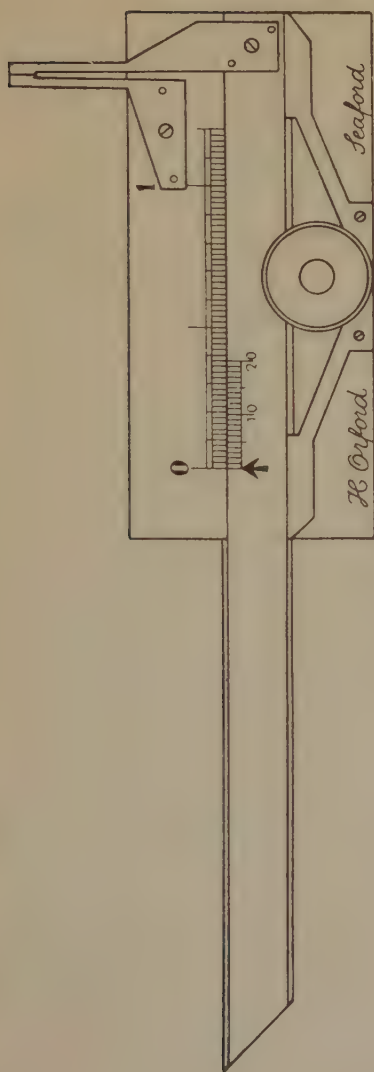


Fig. 231.

measurements a handy little slide-gauge is shown in Fig. 231. It is simply made, and can be divided by any machine divider.

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